COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

. 6, No. 6 | DECEMBER, 1934 | 25c a copy

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The Effect of Tempering Coal on Its Combustion

Regulation of Steam Temperature by Controlled Gas Flow Part II

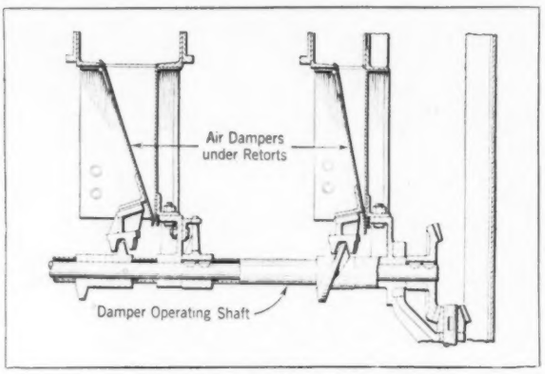
MODERN STEAM PLANT EQUIPMENT

No. 7 *of a series presenting design and operating features of C-E products*

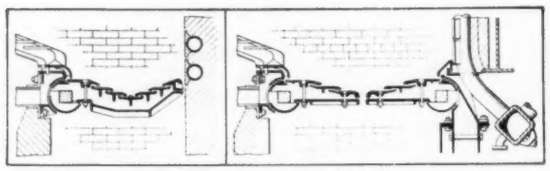
C-E Multiple Retort Stoker

Design MRO

For burning caking, coking and good free-burning bituminous coals



Damper operating mechanism



Arrangements of single and double dump grates

FEATURES

Hopper . . . Sectional frame construction with front and back steel reinforcing plates. Inspection door at each side.

Drive . . . Completely enclosed, compact, spur gear arrangement. May be operated either by electricity or steam.

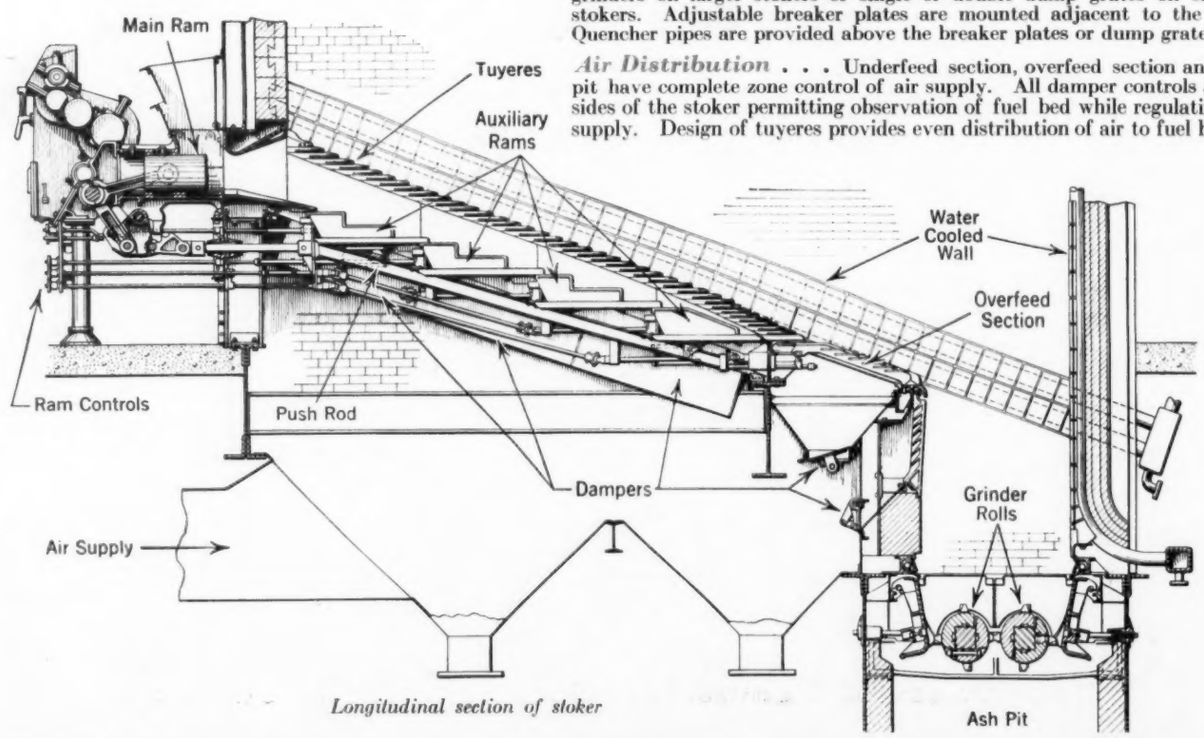
Main Rams and Ram Boxes . . . Cylindrical main rams fit into the ram boxes which are cylindrical at one end and flared at the other to reduce resistance to the coal flow. Ram boxes have provision for proper alignment and have renewable cast-iron liners.

Retorts . . . Sides are built of cast iron, supported on structural steel. Designed to eliminate stresses due to unequal temperatures. Depth gradually reduced toward overfeed section. Auxiliary rams with sifting seals form the bottom of the retorts. The travel of any auxiliary ram can be varied while the stoker is in operation by means of controls conveniently located at the front of the stoker.

Overfeed Section . . . Grate bars alternately moving and fixed at the lower end of the retorts form an overfeed section which evenly distributes the fuel bed and permits complete burning out of combustible before discharge to the ash pit. The length of the stroke of the moving bars is controlled at the front of the stoker. Bars are easily removed.

Ash Discharge . . . Effected by double-roll, ratchet-drive clinker grinders on larger stokers or single or double dump grates on smaller stokers. Adjustable breaker plates are mounted adjacent to the rolls. Quencher pipes are provided above the breaker plates or dump grates.

Air Distribution . . . Underfeed section, overfeed section and ash pit have complete zone control of air supply. All damper controls are at sides of the stoker permitting observation of fuel bed while regulating air supply. Design of tuyeres provides even distribution of air to fuel bed.



Longitudinal section of stoker

COMBUSTION ENGINEERING COMPANY, INC

200 Madison Avenue, New York, N. Y. . . . *Canadian Associates, Combustion Engineering Corporation, Ltd., Montreal*

MANUFACTURING PLANTS: The Hedges-Walsh-Weidner Company, Chattanooga, Tenn.; Heine Boiler Company, St. Louis, Mo.; Coshocton Iron Company, Monongahela, Pa.; Raymond Brothers Impact Pulverizer Company, Chicago, Ill.

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COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

VOLUME SIX NUMBER SIX

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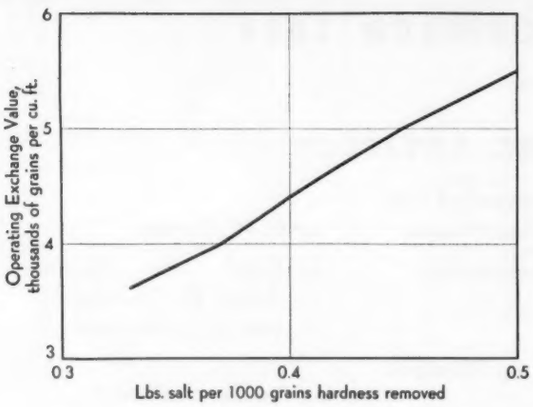
SUPER

A NEW AND



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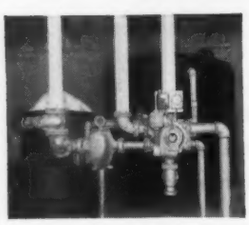

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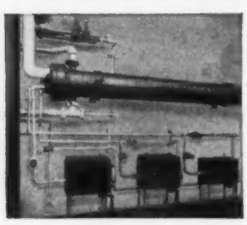

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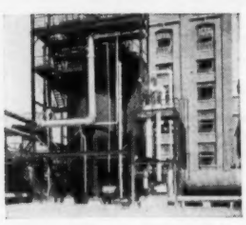

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EDITORIAL

The Utilities Problem

AFTER three years study, involving many field surveys, the New York Power Authority has completed and placed in the hands of the President and the Governor its report on the cost of distribution and electric rates within the state. Filing of the report at this time is expected to influence the action of Congress when the St. Lawrence Treaty comes up for ratification in January, and thus back up the Administration's efforts to this end. Moreover, it is understood that detailed figures are being made available to the mayors of a number of cities within this and other states.

To date only a summary of the report has been made public. This contends that rates for electricity throughout the state are too high; that they could and should be reduced by nearly one half, based upon generating and distribution costs as determined by the survey and fixed charges of six per cent return on *useful fixed capital* and five and one-half per cent allowance for depreciation, taxes and insurance.

One of the major contentions is that the utilities are carrying too much useless and obsolete equipment, as part of the capital account, the fixed charges upon which help to maintain the present rates. Also, it is claimed that overhead is too high.

While it is a comparatively simple matter to determine the cost of generating electricity, which for a given size and type of plant and load conditions is quite generally known to engineers, the distribution costs and commercial expenses have always tended to complicate the compilation of a rate structure. Furthermore, these latter factors differ greatly with locality, and while the distribution figures contained in the report may be informative and useful to some extent, the futility of applying a "single yardstick" to these factors is apparent.

That part of the report which is likely to be questioned most by engineers is the provision of five and one-half per cent to cover depreciation, taxes and insurance. This may hold for a hydro plant, but with steam-plant practice progressing as it has in the last ten years, the obsolescence factor looms large; also, with private utilities already heavily taxed by Federal, State and Municipal Governments, and politicians regarding them as a target for emergency revenue, this percentage is inadequate.

One fails to find in the summary any provision for development without which the present high efficiency of central station practice would have been impossible. It would be most unfortunate to foster upon the utilities such rates as would strangulate further progress and thus ultimately defeat the possibility of subsequent rate reductions through further economies in generation.

The report has received wide publicity in the daily press and its conclusions will be accepted at face value by the average citizen despite the fact that the Power Authority is made up of two lawyers, a college professor and a member of the State Grange. It is manifestly aimed at justifying St. Lawrence power and will undoubtedly prove a most useful instrument to this end.

Following by two days the release of the New York Power Authority's report, comes a report by the Federal Power Commission to the Senate reviewing the propaganda activities of the utilities. Much of this is based on past history, involving the old National Electric Light Association, but the effect is obviously calculated to disarm rebuttal of the former report. It would seem that the Government is rapidly learning the art of adroit propaganda to an extent that makes the old utility interests appear as amateurs.

While it is probable that in some instances existing rates could be reduced without materially affecting profits or service, because of the greater use of electricity that would be stimulated thereby, in other cases the rates suggested would leave little or nothing for dividends after paying interest on the bonded debt and preferred stock. As the common stock of utilities is widely held by consumers, the net result might well be to their disadvantage.

The utilities are in a precarious position. Because of past practices on the part of a few investment bankers and holding companies, because of present and pending taxation, and because of threatened competition on the part of governmental agencies the public is in no frame of mind to invest in utility securities. On the other hand, the load is very definitely increasing and the need for new equipment to meet this demand efficiently is not far off. Financing of improvements presents a problem.

What is to be done about it? How can the operating companies win back the deserved confidence of their communities and convince them that the whole industry should not be indicted for the past sins of the few. Argument and statistics will have little effect. Action will be more effective than words.

Distribution costs with hydro power are no different than with steam power and to the former must be added transmission costs to centers of distribution. The modern steam plant can produce electricity at the switchboard as cheaply as the hydro plant if proper charges on the much greater investment for the latter are included. Commercial expense is independent of the source of the power. It therefore behooves the utilities to get rid of useless capital investment, and to revise their rate structures wherever possible so as to beat the opposition to the tape, trusting to an increased volume of business to return a reasonable profit.

While savings through reductions in electric bills are likely to be small compared with increased taxation incident to huge Governmental power developments, there is no denying the fact that mass opinion is influenced more by the former.

Regulation of Steam Temperature by Controlled Gas Flow—Part II

THE COMPENSATING SUPERHEATER

The first part of this article, by E. V. Rieder published in the November issue, dealt with the development of superheaters as applied to designs used in the power plants of the Detroit Edison Company and leading up to a new type known as the "compensating superheater." The present article, by Mr. Gordon, discusses the history of steam temperature regulation, the theory and design of the compensating superheater, its application and its operation.

By C. W. GORDON
Advisory Engineer,
The Superheater Company

IN EARLIER times the first consideration of the superheater designer was to install enough surface in the relatively cool gas temperature zones selected. There was small likelihood that a safe temperature would be exceeded. With increasing knowledge in design, superheaters were moved to the top of the first pass in a horizontal water-tube boiler or a similar location in a semi-vertical boiler. In these new locations provision was often made to inject water into the steam to limit the steam temperature should conditions cause it to rise above the maximum which could be used. This practice generally resulted in either scale formation or corrosion. Another expedient was to provide a gas by-pass around the superheater so that, as required, only part of the gas would pass over superheater surface. In the following discussion the term "limiting type" refers to superheaters equipped with either a desuperheater of some form, or a gas by-pass.

After many years, experimental installations were made in the interdeck location on horizontal water-tube boilers and the behind bank location on semi-vertical boilers. It was found that the temperature-load curve became fundamentally flatter as the superheater was moved nearer the furnace. This follows the law that to obtain a relatively flat curve, the superheater surface must be located in close proximity to the boiler surface which generates the largest part of the steam output. As a result of this discovery limiting devices passed out of favor for the time being.

To follow the above law to its logical conclusion the intertube design was developed. This design has been extensively used and has given the flattest curve of any standard design available at the present time.

The four types of superheaters described above are illustrated by the typical designs of Figs. 12, 13, 14 and 15.

Fig. 12 illustrates a straight convection superheater as applied to a horizontal water-tube boiler.

Fig. 13 illustrates a typical interdeck design.

Fig. 14 illustrates a behind bank design for a semi-vertical boiler. This design corresponds to the interdeck design of Fig. 13.

Fig. 15 illustrates the intertube design, as applied to a double semi-vertical boiler.

The performance of the superheater designs of Figs. 12, 13, 14 and 15 is shown in Fig. 16 and so arranged that a comparison can be made with the ultimate curve desired, namely, a horizontal straight line. These curves show a vast improvement in the performance of successive designs. They also show that standard designs alone cannot attain the ultimate goal.

During the past fifteen years, with the exception of a few experimental installations, the maximum steam temperature was limited to 750 F. Recently, power plant designers have successfully used 850 F and are now thinking of 1000 F as the goal. With these increases in temperature, it has become imperative to reduce the variation in steam temperature over the load range to the minimum. This insistent demand has resulted in the revival of the old temperature limiting arrangements, in many cases equipped with automatic control. The inherent deficiency of these designs still exists in their modern form, namely, the installation of an excess of superheater surface and the dissipation of the superheating effect of this excess at all loads above the minimum. To provide a scientific approach to the problem, the compensating superheater has been developed and proved in actual practice.

Theory and Design of the Compensating Superheater

The compensating superheater provides a simple and practical method for regulating the steam temperature by controlled gas flow. The theory on which the design is based may be best understood by a study of the diagrams of Fig. 17 in which the compensating superheater is compared with the standard forms. For purposes of comparison the following assumptions are made:

1. The total superheater surface is the same in all cases except as otherwise noted in Diagram E.
2. The gas temperature entering the superheater surface is the same in all cases at a given load.
3. The surface arrangement is such that the gas velocity is the same in all cases at a given load.
4. The combined velocity and mean temperature

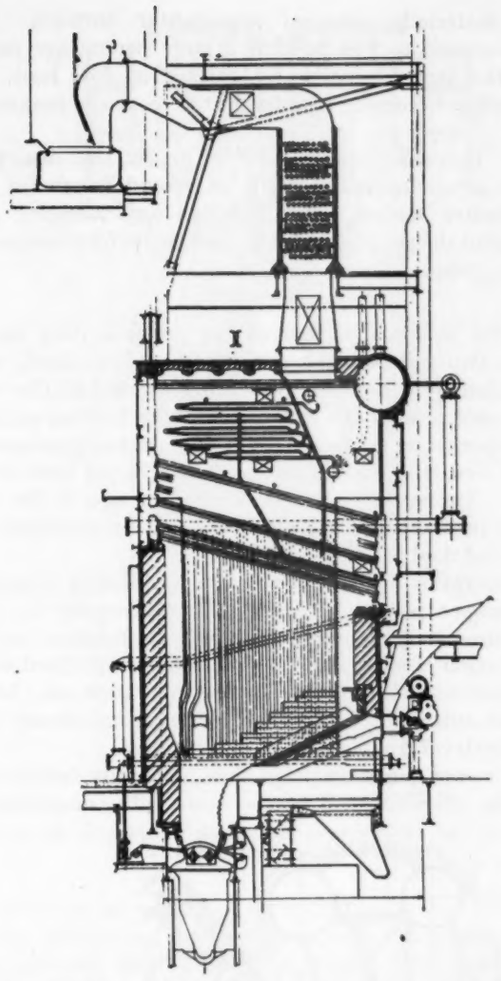


Fig. 12—Straight convection superheater as applied to a horizontal water-tube boiler

difference factor is taken as 0.80 for minimum load and 1.00 for maximum load. These figures are obtained in actual practice. (As the load increases the ratio of gas weight to steam weight remains substantially constant. The steam temperature, however, increases due to the combined effect of increased gas and steam velocities and increased gas temperature).

5. The superheating effect (as indicated by the final steam temperature), is then proportional to the product of *per cent of total gas flow* times *per cent of total surface* times *velocity and mean temperature difference factor.*

When the italicized products are equal at minimum and maximum loads the same final steam temperature will be obtained at both loads and the temperature-load curve will take the form of a horizontal straight line.

Diagram A

This is the simple single bank superheater. The surface is considered as divided into two equal parts by an imaginary baffle. The ratio sums, indicating the superheating effect, follow:

Minimum Load	Maximum Load
0.50 × 0.50 = 0.250	0.50 × 0.50 = 0.250
0.50 × 0.50 = 0.250	0.50 × 0.50 = 0.250
0.500 × 0.80 = 0.400	0.500 × 1.00 = 0.500

Diagram B

This is the simple superheater divided into two equal banks. Operation with equal and unequal gas flow is given to show that no compensating effect can be obtained with this arrangement. The ratio sums for both cases follow:

With Equal Gas Flow at All Loads

Minimum Load	Maximum Load
0.50 × 0.50 = 0.250	0.50 × 0.50 = 0.250
0.50 × 0.50 = 0.250	0.50 × 0.50 = 0.250
0.500 × 0.80 = 0.400	0.500 × 1.00 = 0.500

With Unequal Gas Flow at Minimum Load

Minimum Load	Maximum Load
0.75 × 0.50 = 0.375	0.50 × 0.50 = 0.250
0.25 × 0.50 = 0.125	0.50 × 0.50 = 0.250
0.500 × 0.80 = 0.400	0.500 × 1.00 = 0.500

Diagram C

This is the compensating superheater in which the surface is divided so that 25 per cent appears on the right side and 75 per cent on the left. This surface division is purely arbitrary and will vary in different designs. It will depend on the degree of correction desired. The ratio sums are given for equal and unequal gas flows. With equal gas flow the results are the same as found for Diagram B. The temperature-load curve is a horizontal straight line with unequal gas flow the superheating effect at minimum load is substantially greater than that found for Diagram B. The gas flow may be equalized at maximum load or at some lower point. In the latter case the gas flow must be unequalized in the opposite direction at maximum load to provide a constant steam temperature.

With Equal Gas Flow at All Loads

Minimum Load	Maximum Load
0.50 × 0.25 = 0.125	0.50 × 0.25 = 0.125
0.50 × 0.75 = 0.375	0.50 × 0.75 = 0.375
0.500 × 0.80 = 0.400	0.500 × 1.00 = 0.500

With Unequal Gas Flow at Minimum Load

Minimum Load	Maximum Load
0.25 × 0.25 = 0.0625	0.50 × 0.25 = 0.125
0.75 × 0.75 = 0.5625	0.50 × 0.75 = 0.375
0.625 × 0.80 = 0.500	0.500 × 1.00 = 0.500

Diagram D

This is a compensating superheater design in which the surface is confined to one bank. The surface division may be obtained by baffle design or by shaping the superheater units. This design is particularly applicable to single boilers. The ratio sums are the same as found for Diagram C.

Diagram E

This is the by-pass superheater, one form of the steam temperature limiting type. All of the surface is confined to one bank which is considered to be divided into two equal parts by an imaginary baffle. The minimum surface is required when all of the gas is passed over the superheater side at minimum load and an increasing amount by-passed as the load increases. The by-pass superheater design, as compared with the others, therefore, requires that the surface be increased so that the maximum desired temperature will be obtained at minimum load. In comparison the compensating superheater requires little, if any, increase in surface since it is designed to give maximum temperature at maximum load.

Two methods of designing and operating the by-pass superheater are illustrated in the following examples. In the first case the surface is 25 per cent greater than that of the simple superheater of Diagram A. This

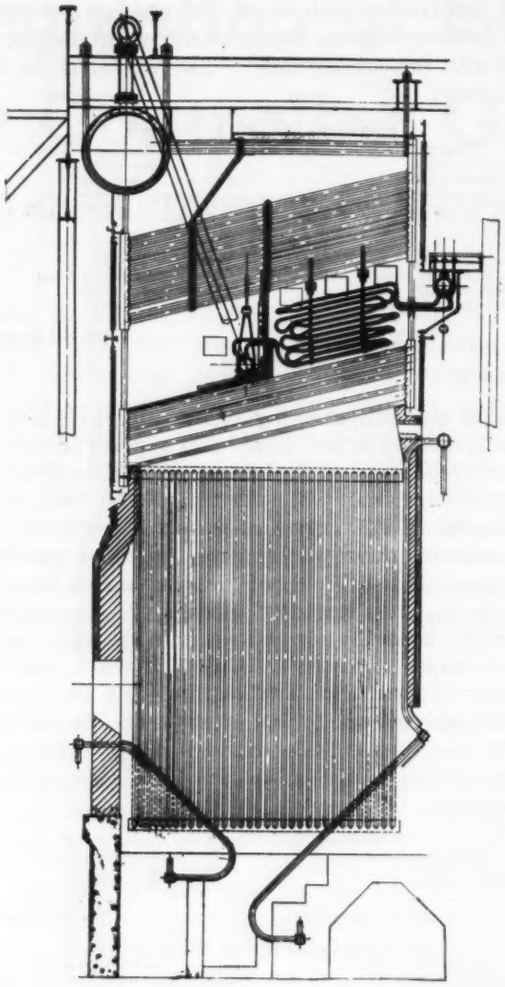


Fig. 13—Typical interdeck design of superheater

gives the same result as the compensating superheater of Diagram C when 100 per cent of the glas flows at minimum load over the superheater side and 80 per cent at maximum load. As such unequal gas flow division at the higher loads will overly penalize the steam generating unit, a second method is shown. In this case the surface is increased by 47 per cent, while 85 per cent of the gas is required to pass over the superheater side at minimum load and 68 per cent at maximum load.

With Surface Increased by 25 Per cent

Minimum Load		Maximum Load
0.50 × 0.625 = 0.3125		0.40 × 0.625 = 0.250
0.50 × 0.625 = 0.3125		0.40 × 0.625 = 0.250
0.625	× 0.80 = 0.500	0.500 × 1.00 = 0.500

With Surface Increased by 47 Per cent

Minimum Load		Maximum Load
0.425 × 0.7353 = 0.3125		0.34 × 0.7353 = 0.250
0.425 × 0.7353 = 0.3125		0.34 × 0.7353 = 0.250
0.625	× 0.80 = 0.500	0.500 × 1.00 = 0.500

Definitions

On the basis of these comparisons, the following definitions are drawn:

1. "Simple Superheater."—This is the standard design in which all of the gas, in unvarying percentage, flows over superheater surface at all loads.

2. "Compensating Superheater."—This is the design in which all of the gas, at all loads, flows in two paths over materially unequal superheater surfaces. The gas is caused to flow so that a large percentage passes over the larger superheater surface at low load, the percentage becoming equalized at or near the maximum load.

3. "By-pass Superheater."—This is the design in which an independent path is provided around the superheater surface through which an increasing percentage of the gas passes as the load varies from minimum to maximum.

Operation

In the practical design of the compensating superheater two independent gas paths are provided, each controlled by a damper, preferably located in the relatively cool zone at the exit to the boiler heating surface. The superheater surface is divided so that approximately 25 per cent is located in one path and 75 per cent in the other. The surface may be located in any of the well known positions and the design is equally applicable to single and double boilers.

In operation the gas flow is unequalized by changing the damper positions to the extent necessary to give the desired steam temperature. The superheater surface distribution is such that the gas flow is equalized at or near maximum load. The damper operation may be by hand or automatic control. Experience has shown that no water level troubles will be encountered.

The steam generating unit may be readily designed so that the efficiency will be the same with compensating

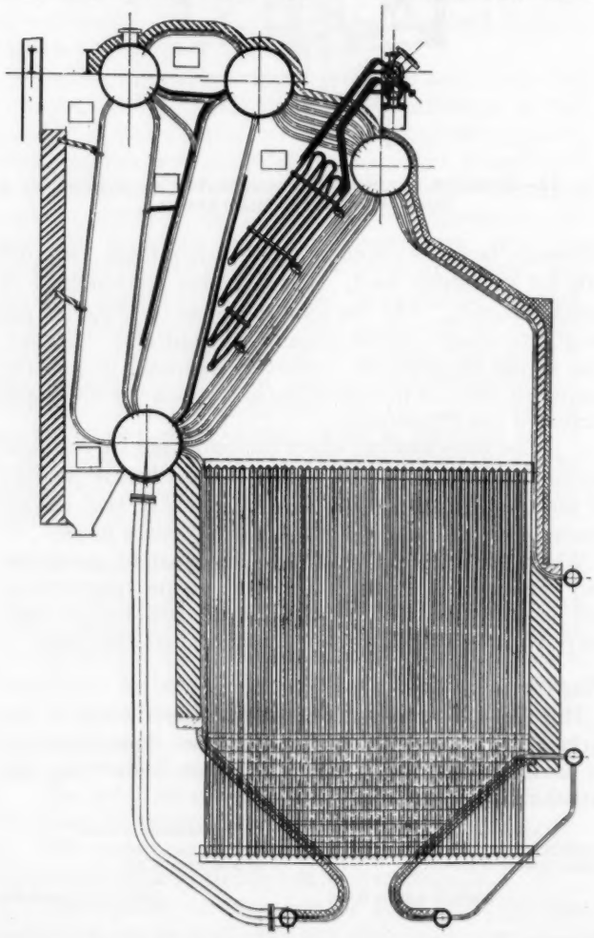


Fig. 14—A behind bank design of superheater for a semi-vertical boiler

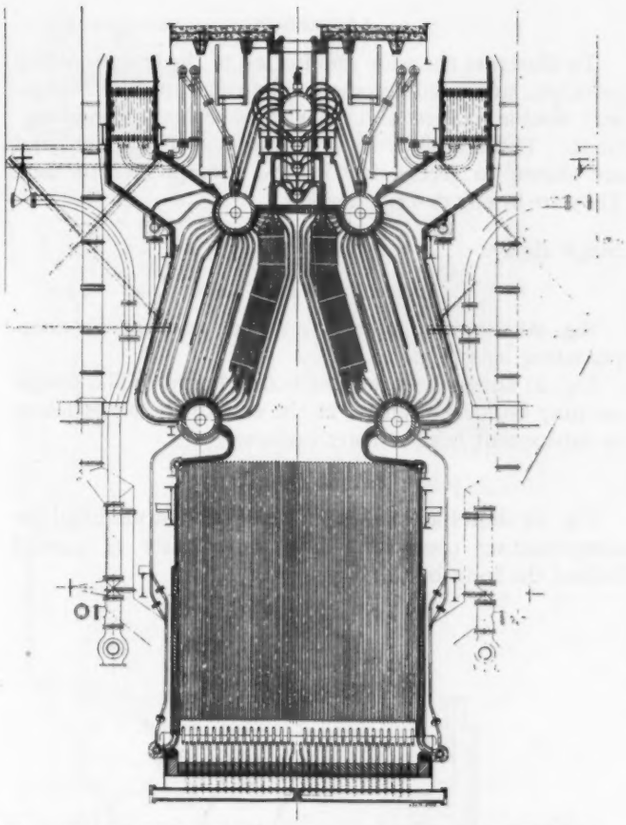


Fig. 15—Intertube design of superheater as applied to a double semi-vertical boiler

operation as with any other method. For loads below the maximum, the induced-draft fan horsepower requirement will be slightly greater with compensating than with standard operation, but materially less than with by-pass operation. Since, however, with the compensating design the flow is equalized at maximum rating, no increase in fan size is required.

In practical operation there is encountered a troublesome day to day variation in steam temperature due to slagging and fly-ash accumulation on the evaporating surfaces. With the compensating superheater design this condition is easily corrected by resetting the dampers.

For best station performance it is usually found neces-

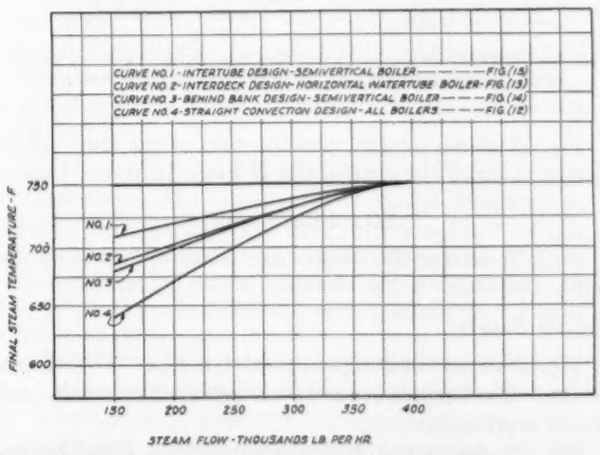

CURVE NO. 1 - INTERTUBE DESIGN - SEMIVERTICAL BOILER ——— FIG. (15)
CURVE NO. 2 - INTERDECK DESIGN - HORIZONTAL WATERTUBE BOILER - FIG. (13)
CURVE NO. 3 - BEHIND BANK DESIGN - SEMIVERTICAL BOILER ——— FIG. (14)
CURVE NO. 4 - STRAIGHT CONVECTION DESIGN - ALL BOILERS ——— FIG. (12)
FINAL STEAM TEMPERATURE - F
750
700
650
600
NO. 1
NO. 2
NO. 3
NO. 4
150
200
250
300
350
400
STEAM FLOW - THOUSANDS LB. PER HR.

Fig. 16—Performance of designs show in Figs. 12 to 15 inclusive

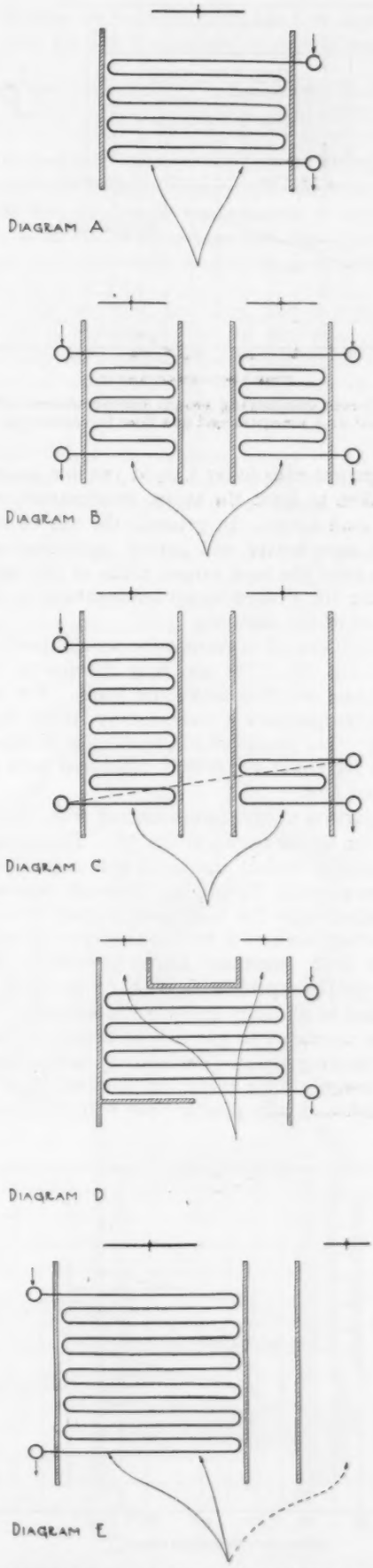


Fig. 17—Diagrams comparing compensating superheater with standard designs

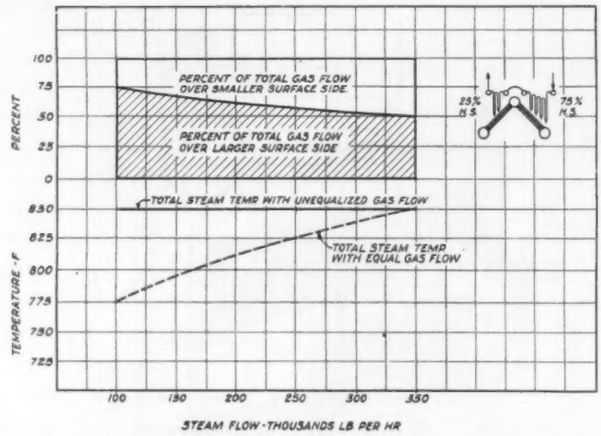

PERCENT OF TOTAL GAS FLOW OVER SMALLER SURFACE SIDE
PERCENT OF TOTAL GAS FLOW OVER LARGER SURFACE SIDE
25% H.S.
75% H.S.
TOTAL STEAM TEMP WITH UNEQUALIZED GAS FLOW
TOTAL STEAM TEMP WITH EQUAL GAS FLOW
PERCENT
TEMPERATURE - F
STEAM FLOW - THOUSANDS LB PER HR

Fig. 18—Curves comparing steam temperatures with equal gas flow and unequalized gas flow for assumed case

sary to operate with lower CO_2 at the low loads. This step is taken to limit the steam temperature variation over the load range. In general, the use of the compensating superheater will permit operating with the same CO_2 over the load range, while at the same time maintaining the desired steam temperature by changing the position of the dampers.

The conditions of operation for an assumed case are shown in Fig. 18. The gas flow division is 75–25 at minimum and 50–50 at maximum loads. For this case the steam temperature is increased by 75 deg F at minimum load. The great value of this design is shown when the curve for equal gas flow is compared with that for unequalized flow.

A comparison of the compensating with the limiting type is given by the curves of Fig. 19. The curve for the limiting type is typical and holds true regardless of the method employed. It will be observed that with the compensating type the maximum correction occurs at minimum load while with the limiting type the maximum correction is at maximum load. Obviously, with the limiting type the superheating effect of part of the surface is dissipated at all loads above the minimum. Furthermore, the resistance to gas flow is materially increased with the limiting types. Particularly is this true of the by-pass design. As a result the induced-draft fan size must be substantially greater than with the compensating type.

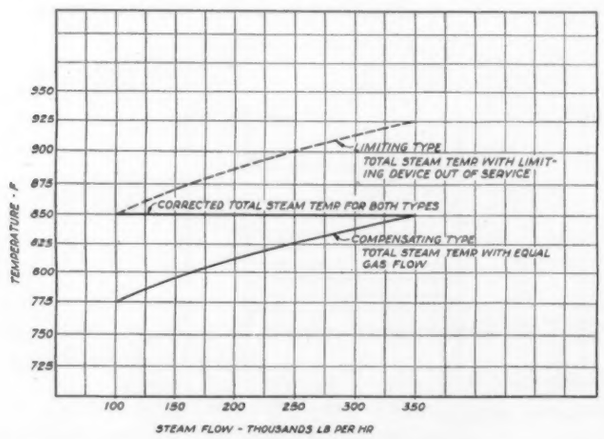

LIMITING TYPE
TOTAL STEAM TEMP WITH LIMITING DEVICE OUT OF SERVICE
CORRECTED TOTAL STEAM TEMP FOR BOTH TYPES
COMPENSATING TYPE
TOTAL STEAM TEMP WITH EQUAL GAS FLOW
TEMPERATURE - F
STEAM FLOW - THOUSANDS LB PER HR

Fig. 19—Performances of compensating and limiting types compared

Application

To illustrate the wide application of the compensating principle, suggested designs are shown as applied to single and double boilers and to various reheater combinations. These designs by no means cover the field and are shown to give a few typical examples of the art. They are briefly described below:

Single Boilers

Horizontal Water-Tube

Fig. 20 shows an interdeck design modified for compensating operation.

Fig. 21 shows a single-pass boiler design. The dampers may be located either at the exit to the superheater or subsequent heat transfer surface.

Semi-Vertical

Fig. 22 shows a three-drum boiler design modified for compensating operation. The superheater is located behind the front bank.

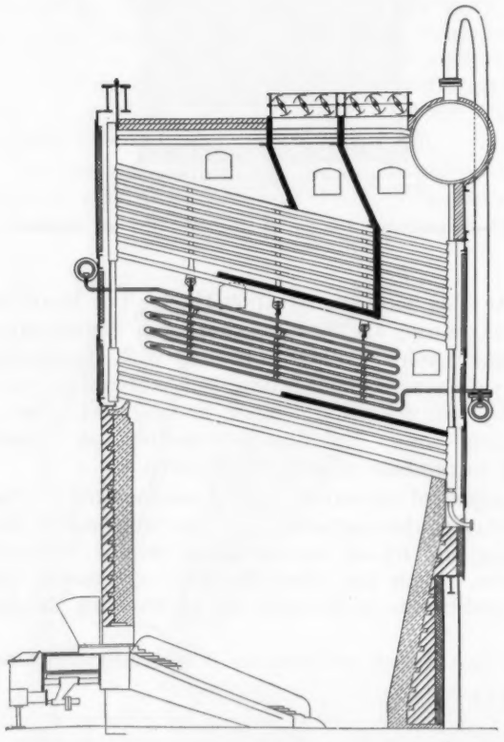


Fig. 20—Interdeck design modified for compensating operation as applied to a horizontal water-tube boiler

Fig. 23 shows another modification of the three-drum design in which the superheater is divided into two banks.

Steam Generator

Fig. 24 shows the slight modification necessary to apply the design to the standard steam generator.

Double Boilers

Fig. 25 shows the design applied to a type "W" Stirling boiler. The surface is partly semi-radiant intertube and partly convection.

Fig. 26 shows the design applied to a Ladd boiler. The entire surface is semi-radiant intertube.

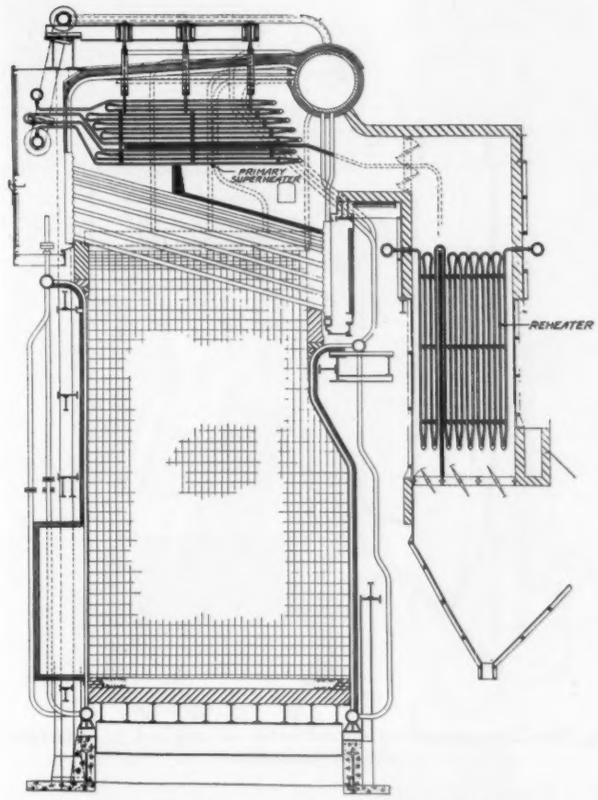


Fig. 21—Single-pass boiler in which dampers may be located at exit to the superheater or subsequent heat transfer surface

Gas Reheater Combinations

Fig. 23 shows an arrangement in which the primary superheater is of the compensating convection type, while the reheater is of radiant surface entirely. Obviously, the arrangement could be reversed if desired.

Fig. 21 shows an arrangement in which both the primary superheater and reheater are of the compensating type. Two methods of design and operation are possible.

In the first case, the superheater surface distribution, or the ratio of large surface to small surface for the primary superheater will be used for the reheater also. Dampers will be provided at the exit to both surfaces and the steam temperature from each independently controlled.

In the second case, the baffle will be extended as shown in the dotted line and the ratio of surface in the two paths will be greater in the reheater section to compensate for the more pronounced convection characteristic. One set of dampers at the exit to the reheater surface will be required.

Conclusions

In conclusion, the advantages of steam temperature regulation by controlled gas flow, as exemplified by the compensating superheater, can be briefly summarized:

A—Design

1. When the compensating design is compared with the standard superheater types.
   - *a.* In general, little increase in superheater surface is required for a given temperature at maximum load.
   - *b.* The boiler symmetry is not appreciably disturbed since the average of unequalized gas flow over the entire load range is not great.
   - *c.* No increase in induced draft fan size is required since the gas flow is equalized at or near maximum load.

2. When the compensating design is compared with superheaters equipped with steam temperature limiting devices.
   - *a.* The superheater surface required is substantially less for the compensating type since it is designed for maximum temperature at maximum load while the temperature limiting type is designed for maximum temperature at minimum load.
   - *b.* The draft loss and, therefore, the induced draft fan size is materially less for the compensating type since the maximum correction occurs at minimum load while with the limiting type the maximum correction is required at maximum load.

B—Operation

1. A final steam temperature versus boiler output curve in the form of a horizontal straight line can be obtained throughout the operating load range.

2. In the case of boilers equipped with standard superheaters, the steam temperature at a given load increases as the evaporating surfaces become dirty, necessitating flue blowing and hand lancing of the evaporating surfaces. With the compensating super-

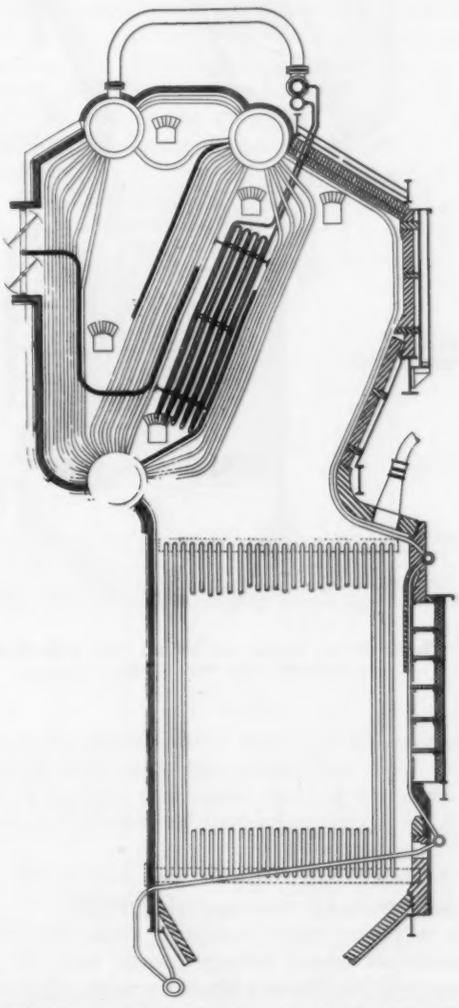


Fig. 22—Semi-vertical three-drum boiler modified for compensating operation

heater installation, this variation can be corrected by a different adjustment of the dampers.

3. With the standard type of superheaters, it is often found that the increased steam temperature obtained by operating the boilers with low CO_2 at low ratings increases the turbine efficiency enough to more than compensate for the decreased boiler efficiency, thereby giving a small net gain. With the compensating superheater, this gain resulting from higher steam temperature is obtained without sacrificing boiler efficiency.

4. The only extra operation necessary in firing these boilers is the change in the relative adjustments of the

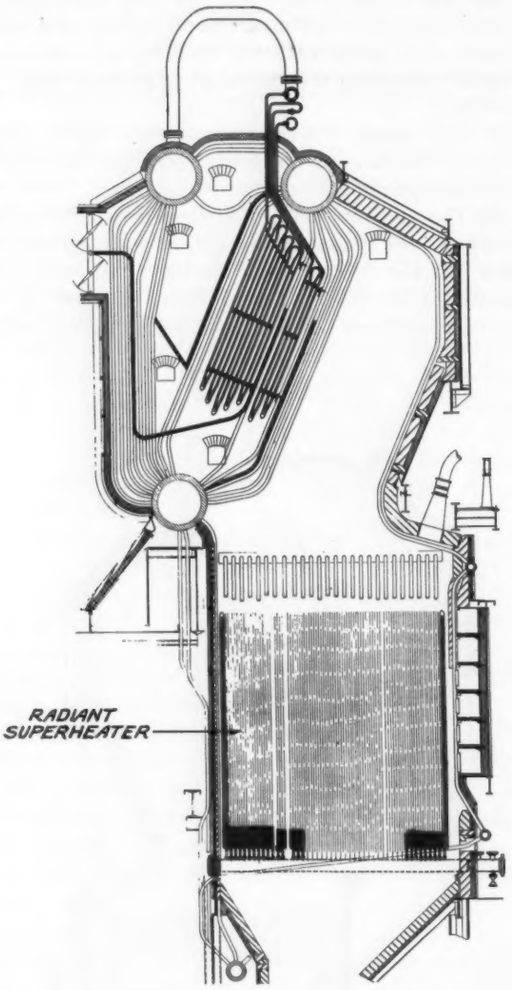


Fig. 23—Three-drum boiler in which the superheater is divided into two banks

two dampers as the load is increased or decreased. After the boiler and superheater have been tested and in operation for a short time, the necessary damper positions for any given load are known and adjustments can be made very rapidly.

5. The regulating dampers are located in a relatively cool zone and give no operating trouble.

6. In a power plant equipped with compensating superheaters, it would be possible to hold the steam temperature at the turbine throttles relatively constant. Since there would be less variation in temperature with such an installation, a higher average value would be

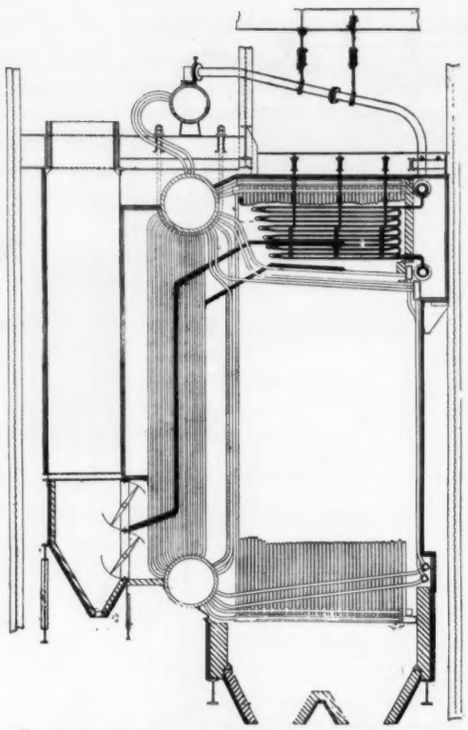


Fig. 24—Compensating superheater as applied to standard steam generator

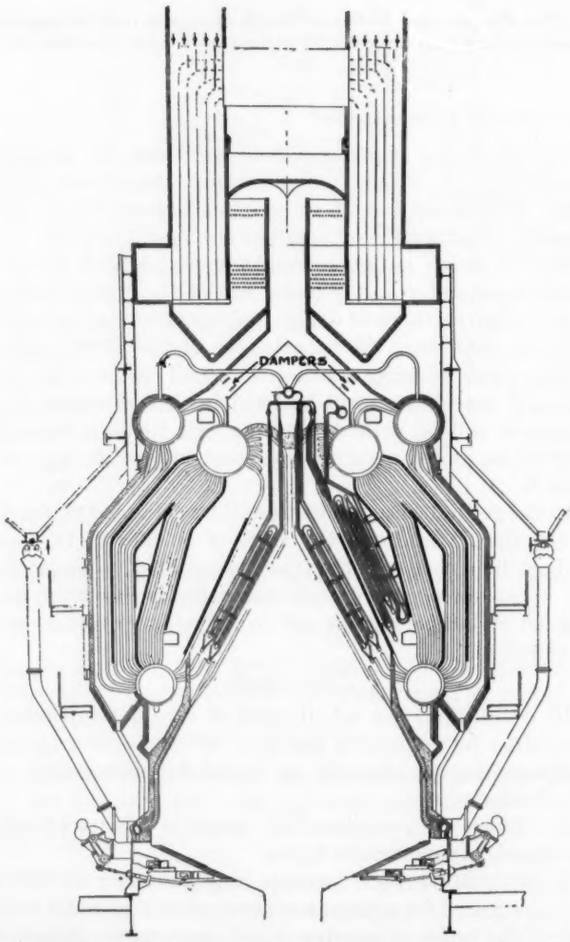


Fig. 25—Compensating superheater as applied to a type "W" Stirling boiler. The surface is partly semi-radiant intertube and partly convection

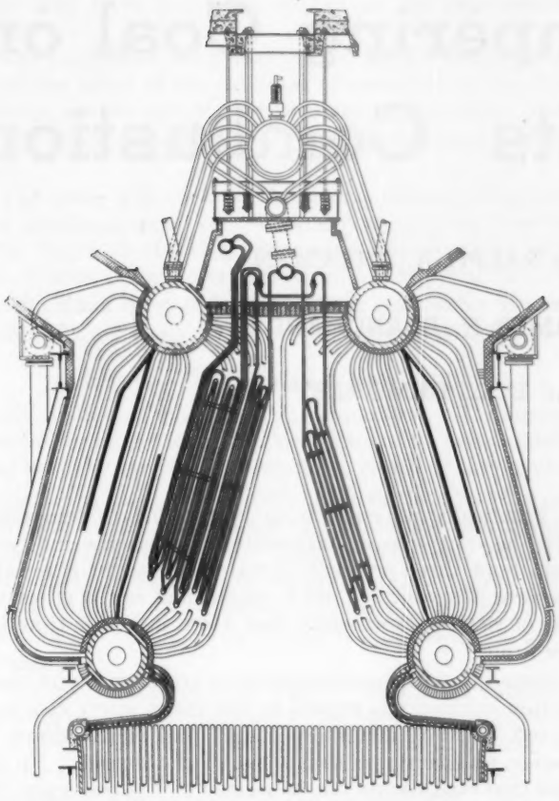


Fig. 26—Showing application of compensating superheater to Ladd boiler, the entire surface being semi-radiant inter-tube design

obtained. This would result in a two-fold advantage: first, a saving in steam consumption; second, a reduction in moisture content, and therefore in the erosive effect in the last turbine stages.

C—Summary

The compensating superheater is a scientific approach to the problem of temperature regulation as it provides the ideal steam temperature curve with the most economical surface arrangement employed at maximum efficiency at all loads and with the minimum of change in design and operation of the steam generating unit.

Engineering History Division. To encourage the collection of source material and the preparation of narrative and biographical data relating to the history of engineering in the Chicago district, the Western Society of Engineers has organized an Engineering History Division. This is somewhat of an innovation among engineering society activities and might well be emulated by groups in other localities.

The Smoke Abatement Exhibit which attracted wide attention during the 1934 Century of Progress is to be installed permanently at the Rosenwald Museum of Science and Industry, Jackson Park, Chicago. This exhibit which was sponsored jointly by certain railroads, coal operators and equipment manufacturers is largely educational and as a permanent display should do much to further the cause of smoke elimination.

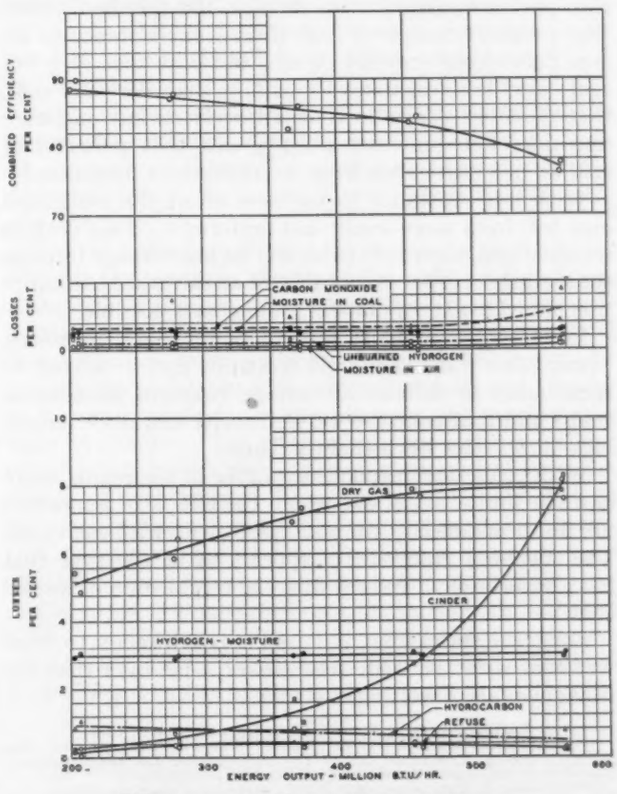
Boiler Test at Hudson Avenue

The accompanying set of test performance curves is from a paper by P. H. Hardie and W. S. Cooper dealing with tests on one of the large steam-generating units at the Hudson Avenue Station of the Brooklyn Edison Company, which is being presented at the Annual Meeting of the A.S.M.E.

The unit tested is of the Ladd type and has 24,450 sq ft of heating surface, 3846 sq ft of furnace water walls, 5740 sq ft of superheater surface and 22,400 sq ft of economizer surface. The furnace volume is 14,000 cu ft. It is fired by a 15-retort, 69-tuyère underfeed stoker having a projected grate area of 694 sq ft. The windbox is equipped with zoned air control which permits hand control of the rate at which air is supplied to the various sections of the grate. One forced-draft fan of 200,000 cfm capacity and two induced-draft fans of 155,000 cfm capacity each serve this unit.

Ten 24-hr tests at five loads were run at outputs ranging from 174,400 to 504,200 lb of steam per hour. The steam pressure at the superheater outlet ranged from 421 to 431 lb per sq in. and the temperature from 706 to 719 F. Coal with a heating value of 13,920 to 14,120 Btu per lb, 3 to 3.7 per cent moisture and 6.6 to 7.7 per cent ash was burned. The pounds of coal per square foot of projected grate surface ranged from 23.8 to 76.2 lb per hr. At the highest output the total power consumed by the boiler auxiliaries was 1285 kw. This corresponds to 2.3 per cent of the coal required. The efficiencies shown by the curve are gross, not net, in that auxiliary power has not been deducted.

It is noteworthy that an output of over a half million pounds of steam per hour at an efficiency of 77 per cent could be maintained for 48 hr.



Efficiency and Energy Balance Curves

The Effect of Tempering Coal on Its Combustion

This investigation was made on a small laboratory furnace with Ohio No. 6, Hocking and Pittsburgh No. 8 coals to determine the effect of addition of moisture on the total volume, on the rate of gas evolution, and on the composition of the gases given off initially. No variation was found in the total volume nor in the composition of the total gases with varying moisture up to 14 per cent. The rate of evolution in the first four minutes was decreased with increased moisture, and there was a decrease in the hydrogen and increase of the hydrocarbon content during the first few minutes due to delayed heating.

By RALPH A. SHERMAN*

JAMES R. BLANCHARD**

and D. J. DEMOREST***

THE tempering of coal, that is, the addition of water to the coal, has long been a more or less widely practiced custom, particularly in the Middle West. The original purpose of wetting the coal was probably to decrease the dust incident to handling, but firemen noted that better combustion was obtained with the wet than with dry coal.

Frequent references are found in the technical literature to the practice of tempering in which various reasons for the improvement are cited. Marsh (*1*), as a result of a series of tests to determine the effect of moisture on the pressure drop through the fuel bed, states that properly tempered coal offers less resistance to air flow than either very dry or very wet coal, that very wet coal offers less resistance to air flow than very dry coal, that moisture added to coal is largely surface moisture and does not penetrate deeply, and that particles of coal do not burst open from internal steam formation.

With less resistance to the flow of air the moistened coal will burn more freely and uniformly. Less draft is required and, therefore, there will be less leakage through the setting; a lower excess air and an increased consumption of fuel per square foot of grate area is possible.

From a questionnaire sent to power-plant engineers, Marsh also concluded that moisture can be added to some coals to definite advantage (western bituminous coals) and that coke breeze, anthracite and dock screenings burn better when slightly damp.

With coals that respond favorably to tempering there is a size limitation above which the effects of tempering are not pronounced; the size limit varies with each coal. The traveling grate stoker appears to be the type that has given the most success with the combustion of wetted coal.

Long (*2*) states that it is not advantageous to burn wet coal with the underfeed stoker. He says that the fundamentals of wetting coal are:

"Practically all coals burn better due to tempering with the exception of anthracite. Experience indicates that about three per cent of water by weight is usually the most desirable. Time is an element in the effectiveness of wetting down coal—wet down in ample time before firing."

Arms (*3*) sent questionnaires to consumers and combustion engineers in regard to the place where coal was wetted. The replies showed that coal is wet down in storage, on a conveyor and in the stoker hopper. He advises that coal should not be wetted on the conveyor due to the effect of sulphur acids. If the coal is moistened in the stoker hopper, hot water or steam should be used, as their tempering action is more rapid.

He concludes from an experimental investigation of ignition temperatures that, despite the retardation in heating, wet coal reaches the glow point sooner than dry coal, and that the wet coal shows the unusual tendency to flame before the glow point is reached.

Etherton (*4*), Parr (*5*) and others agree that added water tends to hold the fines together and prevents their loss by sifting through the grate or their escape out of the stack unburned.

Haslam and Russell (*6*) and Kreisinger (*7*) say that moisture up to six per cent accelerates gas ionization and reaction. Coates (*8*) says that a higher percentage of CO_2 in the flue gases will be obtained from tempered slack coal.

Haslam and Russell also say that the tempering of coal retards the devolatilization and tends to prevent smoke with its attendant loss of fuel.

Wylde (*9*) states that the increased moisture that comes from the fuel bed of tempered coal reacts with the incandescent carbon particles of the flame. The water vapor that does not react dissociates and extracts heat from the fuel bed and radiates it to the boiler at a higher rate of heat transfer. Undissociated moisture may absorb energy from the fuel bed and radiate heat to the colder parts of the furnace. He presents no experimental data to prove his theories.

The foregoing review of the literature shows that there is general agreement that the tempering of coal has certain physical effects in reduction of siftings, reduction of draft required and in the caking of the fuel. Statements as to the chemical effect of added moisture, either in the delay of the evolution of volatile matter or change in the composition of the gases, have been speculative theories

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*** Professor of Metallurgy, Ohio State University, Columbus, Ohio.
Note—Numbers refer to references at end of text.

only and have not been supported by experimental data.

The purpose of the present investigation was to determine the effect of the addition of moisture on the total volume, on the rate of evolution and on the composition of the gases given off in the initial carbonization of the coal.

The study was made on three coals that are frequently and commonly used on traveling grate stokers from the Ohio No. 6 or Hocking, Pittsburgh No. 8 and Illinois No. 6 beds. Data were taken on air dry coal and coal to which had been added 2 to 14 per cent water in increments of 2 per cent. All tests were run at 1472 F.

Apparatus and Method of Investigation

Fig. 1 shows a diagram of the apparatus. The furnace was not designed for this investigation but was available and had the merit of a large heat capacity and a close control. A particular feature of the furnace was the control which held the furnace at the desired temperature plus or minus 2 deg F. Simpson (*10*) has described the furnace and control in detail. Fig. 2 is a photograph of the furnace, the apparatus for the collection of gas samples and the panel for the control of the furnace temperature.

The carbonization tube was of fused silica supported with its closed end midway in the furnace. A chromel-alumel thermocouple immediately below the tube was the means for determination of the temperature. This was read at $^1/_2$-min intervals during each test.

The sample of coal, 5 grams, was held in a special platinum pan of about 10 cc capacity that had a three-wire support and hook by which it was suspended on a wire through a porcelain tube; the wire was sealed to the top of the tube with de Khotinsky cement. A mercury seal, which is shown in detail at the left of the figure, allowed the sample to be suspended in the cool zone at the top of the tube for the moment required to make the connections and then quickly lowered to the heating zone. Before placing the sample in the tube it was flushed with nitrogen to avoid oxidation of the coal or the gases. When the coal sample was introduced into the

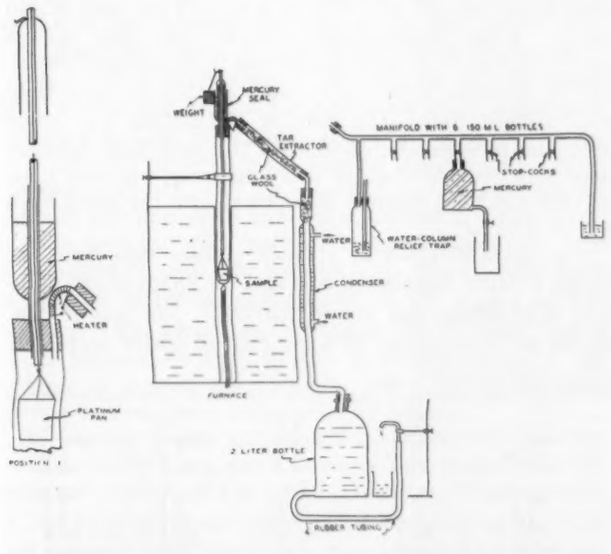

Fig. 1—Diagram of apparatus showing method for determination of volume and, on right, method for collection of samples for analysis

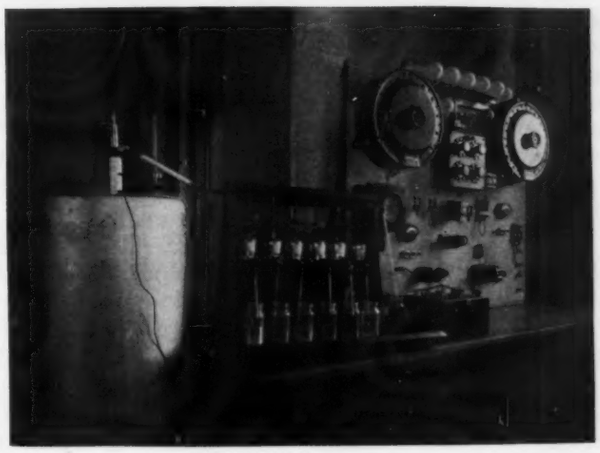

Fig. 2—View of furnace and apparatus for collection of samples; panel for control of furnace temperature on right

distillation tube in the furnace the temperature dropped to about 1440 F and rose to 1472 F in 12 min.

The gas left the distillation tube through a glass tube in the rubber stopper. On the bend of the tube was wound a small heater coil to prevent condensation and refluxing of the tars. The gas then passed through a tube packed with glass wool to collect the tar; the tube was cleaned and repacked before each run. Following was a water-cooled glass condenser to cool the gases.

For the determination of the volume the gas was collected in a 2-liter aspirator bottle to the lower opening of which was connected a rubber tubing terminating in a reversed-U glass tube. As the displaced water flowed from the tube the end was kept level with the water level in the bottle. The water was collected in beakers which were changed at minute intervals; the volume in each being later measured in a graduate. All volumes were corrected to standard conditions of 32 F and 29.92 in Hg.

Each test was continued for 16 min, at which time the rate of gas evolution was very low with all three coals. At the close of the test a sample was taken from the aspirator bottle and stored over mercury for later analysis.

For the collection of samples at minute intervals for analysis the manifold shown at the right of Fig. 1 was connected to the tar extractor. The samples were collected in 150-ml bottles over mercury. The gas evolved during the first minute was not collected, because it was found to be so diluted with nitrogen and air as to render an accurate analysis on the nitrogen and oxygen free basis impossible. The water seal at the right end of the manifold prevented the admission of air and allowed the escape of surplus gas. The trap at the right was to prevent the mercury in the seal on the top of the distillation tube being pulled into the tube if mercury were allowed to run from the sampling bottle too rapidly.

The gases were analyzed for CO_2, O_2, CO, H_2, CH_4 and C_2H_6 in a Bureau of Mines type orsat which used mercury as the displacing fluid. Analyses were calculated to the O_2 and N_2 free basis.

Preparation of Samples

The coals, which had been in dry storage for a year or more, were crushed to pass the 20-mesh sieve and air

dried to constant weight at 115 F. Each sample of coal was divided into eight parts; to each seven parts water was added in amounts of 2 to 14 per cent by increments of 2 per cent. The samples were thoroughly mixed and stored to temper for not less than two weeks before use. The actual amount of moisture in each sample was determined by drying a sample at 221 F at the time of each test.

Table I gives the source, proximate and ultimate analyses and calorific value of the coals used; the analyses are on the air-dried basis.

TABLE I—CHARACTERISTICS OF COAL

Coal	Ohio No. 6 Hocking Valley	Illinois No. 6	Pittsburgh No. 8
Source			
State	Ohio	Illinois	Ohio
County	Athens	Jackson	Belmont
Mine	Lick Run	Kathleen	Blaine
Composition, air dried			
Proximate			
Moisture	2.9	2.7	1.0
Volatile Matter	33.4	29.7	36.6
Fixed Carbon	50.1	53.1	52.4
Ash	13.6	14.5	10.0
	100.0	100.0	100.0
Ultimate			
Carbon	64.4	65.7	70.3
Hydrogen	4.6	4.7	4.9
Oxygen	13.5	12.7	9.2
Nitrogen	1.2	1.3	1.0
Sulphur	2.7	1.1	4.6
Ash	13.6	14.5	10.0
	100.0	100.0	100.0
Calorific value			
Btu per lb	11,480	11,560	12,810

Results of Tests—Volumes of Gas Evolved

Tables II, III and IV present, respectively, for the Illinois, Hocking and Pittsburgh coals the data obtained in the tests to determine the effect of moisture on the total volume of gas evolved. The volumes of gas have been reduced to standard conditions, zero C 760 mm, Hg, and calculated to a common basis of volume of gas per 5 grams of dry coal.

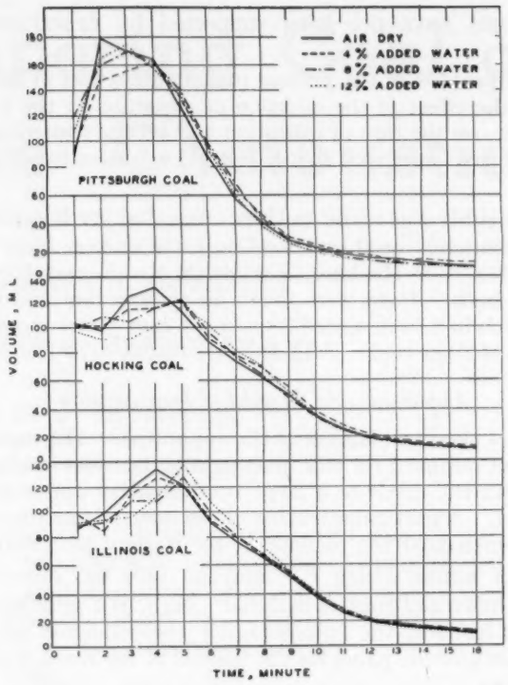

Fig. 3—Rate of gas evolution at 800 C from Illinois, Hocking and Pittsburgh coals with varying moisture content

The data in Tables II, III and IV show that neither the total volume of gas nor the composition of the total gas varied in any consistent manner in relation to the amount of moisture added. The differences among the samples were within the limits of error in duplicate tests.

TABLE II—SUMMARY OF DATA ON ILLINOIS COAL

Added water, per cent	Air dry	2	4	6	8	10	12	14
Total moisture, per cent	2.8	4.4	6.2	8.6	9.8	12.0	13.2	16.4
Total gas per 5 gms dry coal, ml	986	976	984	972	975	989	996	973
Coke per 5 gms dry coal, gms	3.50	3.52	3.50	3.44	3.51	3.55	3.52	3.58
Loss on distillation, per cent	30.0	29.6	30.0	31.2	29.8	29.0	29.8	28.4
Gas composition, O_2 and N_2 free, per cent								
CO_2	5.6	5.3	5.7	4.9	5.0	4.7	4.8	5.0
Unsaturated hydrocarbons	5.0	6.3	6.7	7.5	6.9	6.6	6.9	7.0
H_2	40.4	40.0	39.6	40.4	42.9	43.3	41.8	42.2
CO	14.7	14.0	13.8	14.7	14.7	14.1	14.3	14.3
CH_4	32.6	32.8	34.0	32.0	27.3	31.0	31.1	30.2
C_2H_6	1.6	1.6	0.0	0.7	3.2	0.4	1.4	1.5

TABLE III—SUMMARY OF DATA ON HOCKING COAL

Added water, per cent	Air dry	4	8	12
Total moisture, per cent	3.4	7.5	10.6	11.3
Total gas, per 5 gms, dry coal	974	996	960	935
Coke per 5 gms coal, gms	3.42	3.40	3.47	3.28
Loss on distillation, per cent	31.6	31.9	30.6	34.0
Gas composition, O_2 and N_2 free, per cent				
CO_2		9.0	9.6	10.3
Unsaturated hydrocarbons		7.2	7.9	7.2
H_2		33.7	32.2	32.0
CO		13.9	13.5	14.7
CH_4		33.3	32.6	33.1
C_2H_6		2.9	4.2	2.7

Fig. 3 shows the rate of gas evolution from the three coals when air dry and with 4, 8 and 12 per cent added water. With Hocking and Illinois coal there was a marked effect of the added moisture in the delayed evolution of the gas; it was more marked with Hocking than with Illinois coal. The rate of distillation was lower with the moistened coal during the first four minutes than with the dry coal but was consistently greater later so that the total volume was practically the same with wet or dry coal.

The gases distilled at a much greater rate from the higher volatile Pittsburgh coal and the effect of the addition of moisture was not so marked. Nor was it consistent as the addition of 4 per cent of water decreased

TABLE IV—SUMMARY OF DATA ON PITTSBURGH COAL

Added water, per cent	Air dry	2	4	6	8	10	12	14
Total moisture, per cent	1.2	2.8	4.2	4.9	6.5	8.6	9.4	11.0
Total gas per 5 gms dry coal, ml	1050	1067	1050	1029	1088	1016	1058	1009
Coke per 5 gms dry coal, gms	3.06	3.03	3.06	3.09	3.04	3.08	3.04	3.06
Loss on distillation, per cent	38.8	39.4	38.8	38.2	39.2	38.4	39.2	38.8
Gas composition, O_2 and N_2 free, per cent								
CO_2	9.4	9.4	9.9	10.3	9.1	10.1	8.5	9.6
Unsaturated hydrocarbons	8.7	8.7	8.8	8.7	8.9	9.1	9.0	9.3
H_2	30.8	32.1	32.5	31.1	32.0	30.0	32.4	30.4
CO	9.7	9.8	9.4	9.4	9.6	9.0	9.5	8.8
CH_4	35.2	34.2	32.7	33.3	34.3	34.1	33.2	33.9
C_2H_6	6.2	5.8	6.7	7.2	6.1	7.7	7.3	8.0

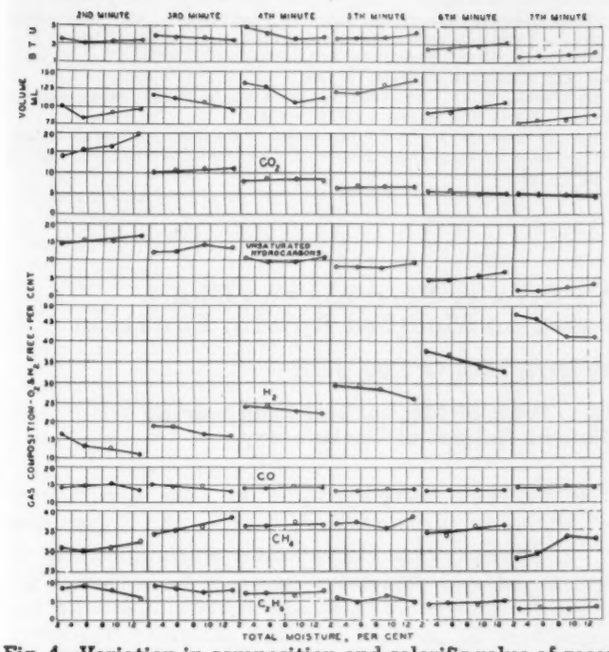

Fig. 4—Variation in composition and calorific value of gases from Illinois coals

the rate of distillation more than the addition of 12 per cent.

Figs. 4, 5 and 6 show, respectively, for the Illinois, Hocking and Pittsburgh coals variation in composition, and heating value of the gases evolved during the second to seventh minutes of distillation of the air dry and tempered coals. In the calculation of the calorific value of the gases the volumes were reduced to the conditions 60 F and 30 in. of mercury, and the following heating values were used in the computation:

Constituent	Btu/cu ft
CO_2	0
Unsaturated hydrocarbons	2500
H_2	325
CO	325
CH_4	1015
C_2H_6	1781

A study of Figs. 4 to 6 shows one outstanding similarity in results, namely the decrease in the percentage of hydrogen with increase in moisture content of the coal. The principal source of the hydrogen is the breaking down of the hydrocarbons. We should expect, therefore, an increase in the hydrocarbons with increase in moisture, and this is seen to be true.

There is a consistent increase in unsaturated hydrocarbons with all coals and, with a few exceptions, an increase in ethane with increase in moisture. The variations in methane with moisture is not so consistent; this is as might be expected because CH_4 and H_2 may both be formed in the breaking down of the higher hydrocarbons. The percentage change in the hydrocarbons is small relative to that in the hydrogen, because one volume of ethane, for example, will give, on complete decomposition, three volumes of hydrogen.

As shown above neither the composition nor the volume of the total gases changed materially with the moisture content of the coal. Therefore, these changes in the hydrogen and hydrocarbon contents in the first few minutes were apparently compensated by later opposite changes in the composition of the gas. The effect of the moisture cannot therefore be ascribed to any chemical reaction but only to delay in heating of the coal.

The percentage of carbon monoxide changed very little with change in moisture.

The percentage of carbon dioxide did not vary materially with the moisture content with the Pittsburgh coal but increased sharply in the second minute with Illinois coal and in the second to fifth minutes with the Hocking coal with increase in moisture. Although the moisture may have favored oxidation of the Illinois and Hocking coals, which are high-oxygen coals and readily oxidized, the fact that the percentage of carbon dioxide in the total gases distilled was not higher indicates that oxidation had not increased with increase in moisture. Rather, the increased moisture apparently favored the liberation at a lower temperature of the carbon dioxide fixed on the coal.

The calorific value of the gases, shown at the top of the figures, shows no entirely consistent relation to the moisture although the trend is a decrease of calorific value with increase in moisture in the second to fourth minutes and an increase in the fifth to seventh minutes.

Conclusions

The data obtained from the carbonization at 800 C of Illinois, Hocking and Pittsburgh coal with varying percentages of moisture may be summarized as follows:

1. No variation was found in the total volume nor the composition of the total gases with varying moisture, up to 14 per cent.

2. The rate of evolution in the first three to four minutes was decreased with increase in moisture, markedly with Illinois and Hocking coals, less markedly with Pittsburgh coal.

3. The most marked change in the composition of the gases during the first seven minutes was the decrease in the content of hydrogen and corresponding increase in the hydrocarbons. As the total volume and composition did not change with moisture content, the changes in composition during the first few minutes were

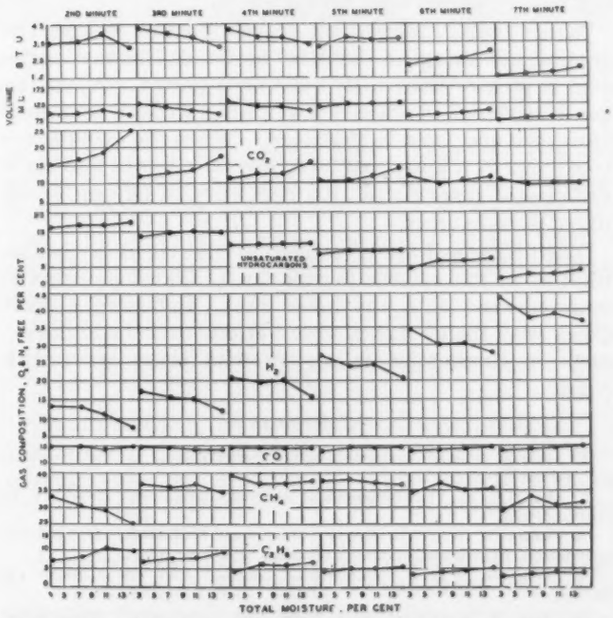

Fig. 5—Variation in composition and calorific value of gases from Hocking coals

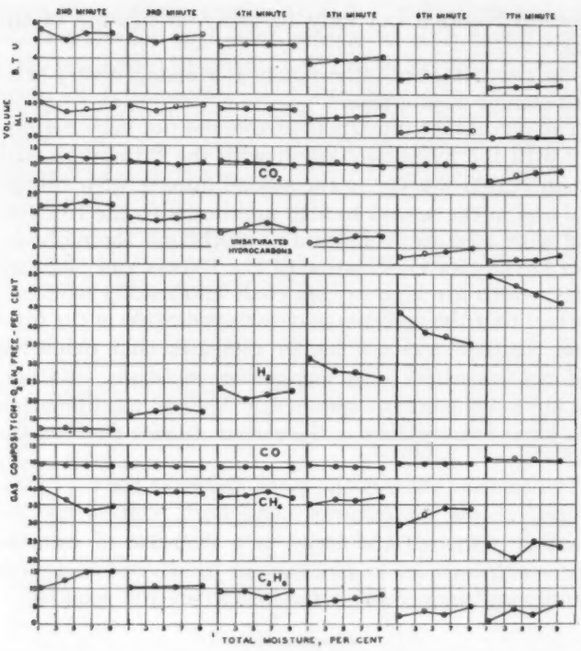

Fig. 6—Variation in composition and calorific value of gases from Pittsburgh coals

indicated to be due to delayed heating rather than chemical reaction.

4. The fixed carbon dioxide in the high-oxygen coals was released at a lower temperature. With this out of the way sooner, earlier ignition is probably favored.

Reference to Fig. 5 will show that although the maximum rate of evolution of gas was almost as great with the tempered as with the dry coal the peak was much sharper with the wet coal. When coal is burned on hand-fired grates and the rate of supply of secondary air is constant and less than required for the maximum rate of evolution the lower average rate of distillation of the combustible will mean that the opportunity will be afforded for more of the gas to burn and the loss due to unburned gas will be less with tempered than with dry coal.

When coal is burned on traveling-grate stokers the possible advantage of the delay in devolatilization of the coal is greater than with hand-fired grates. When the gas is driven off very quickly as with dry coal a deficiency of oxygen may exist in that zone. When the evolution is continued at a lower rate over several minutes and some distance of grate travel, the deficiency of oxygen is not likely to be so great.

The findings of the investigation that the delay in distillation of the volatile matter due to added moisture is more marked with the lower rank, high-oxygen coals check with the published observations that the improvement in combustion is greater with these lower-rank coals.

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Air Density Formula and Chart Based on Modified Apjohn Equation

By NEWTON C. EBAUGH

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Georgia School of Technology

PROFESSOR Berry's articles on "The Accuracy of Humidity Computations" and "A Comparison of Psychrometric Equations" which appeared in the August and September issues of COMBUSTION are of timely interest to those who have to deal with the atmosphere in air flow and fan practice. The comparison of the Apjohn, Ferrel and Carrier equations for vapor pressure in the usual atmospheric range particularly interested the author who had previously compared the Ferrel and Carrier equations but who was not familiar with the Apjohn equation.

In fan practice and in the measurement of air with nozzles, orifices or pitot tubes, it is necessary to know the density of the air flowing and the Apjohn equation, as modified by Professor Berry, may be used to obtain a simple equation for the density.

The density of the air mixture is the sum of the dry air and vapor densities, that is

$$d_m = d_a + d_v$$

where d_m = density of mixture
d_a = density of dry air in the mixture
d_v = density of vapor in the mixture

The density of both the dry air and of the vapor, at the usual vapor pressures attaining in the atmosphere is given with a high degree of accuracy by the perfect gas law as follows:

$$PV = MRT$$

thus

$$d_m = \frac{P_a}{53.3\ T} + \frac{P_v}{85.7\ T} \text{ lb per cu ft}$$

where P_a = dry air pressure in lb per sq ft
P_v = vapor pressure in lb per sq ft
T = dry bulb or mixture temperature in Fahrenheit, absolute
53.3 = gas constant for dry air
85.7 = gas constant for low pressure steam

but $P_a = B - P_v$

where B = barometric pressure

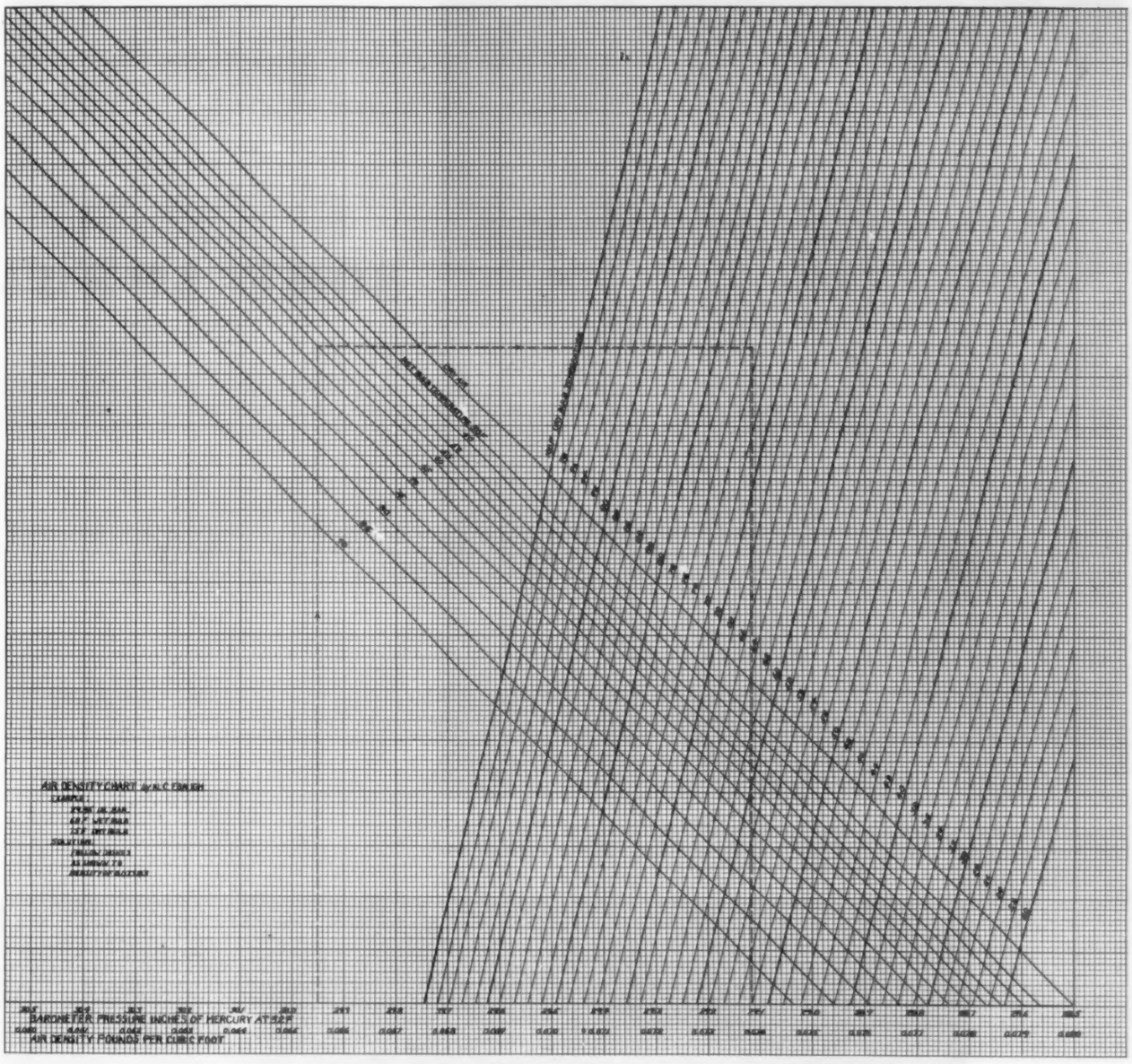
so that

$$d_m = \frac{B - P_v}{53.3\ T} + \frac{P_v}{85.7\ T}$$

$$= \frac{B - 0.378\ P_v}{53.3\ T}$$

Expressing B and P_v in inches of mercury at 32 F rather than in pounds per square foot, and T in degrees Fahrenheit rather than in degrees F abs gives

$$d_m = \frac{B - 0.378\ P_v}{346.5 + 0.7535 t_d} \text{ lb per cu ft} \qquad (1)$$



Chart, based on modified Apjohn equation for determining air density

Now the modified Apjohn equation for vapor pressure is

$$P_v = P_w - \frac{B}{30}\,\frac{(t_d - t_w)}{90}$$

where P_w = saturated vapor pressure at the wet bulb temperature
t_d = dry bulb temperature, F
t_w = wet bulb temperature, F

Substituting this relation in equation (1) gives

$$d_m = \frac{B - 0.378\left[P_w - \frac{B}{30}\,\frac{(t_d - t_w)}{90}\right]}{346.5 + 0.7535\,t_d}$$

Which reduces to

$$d_m = \frac{B[1 + 0.00014\,(t_d - t_w)] - 0.378\,P_w}{346.5 + 0.7535\,t_d} \qquad (2)$$

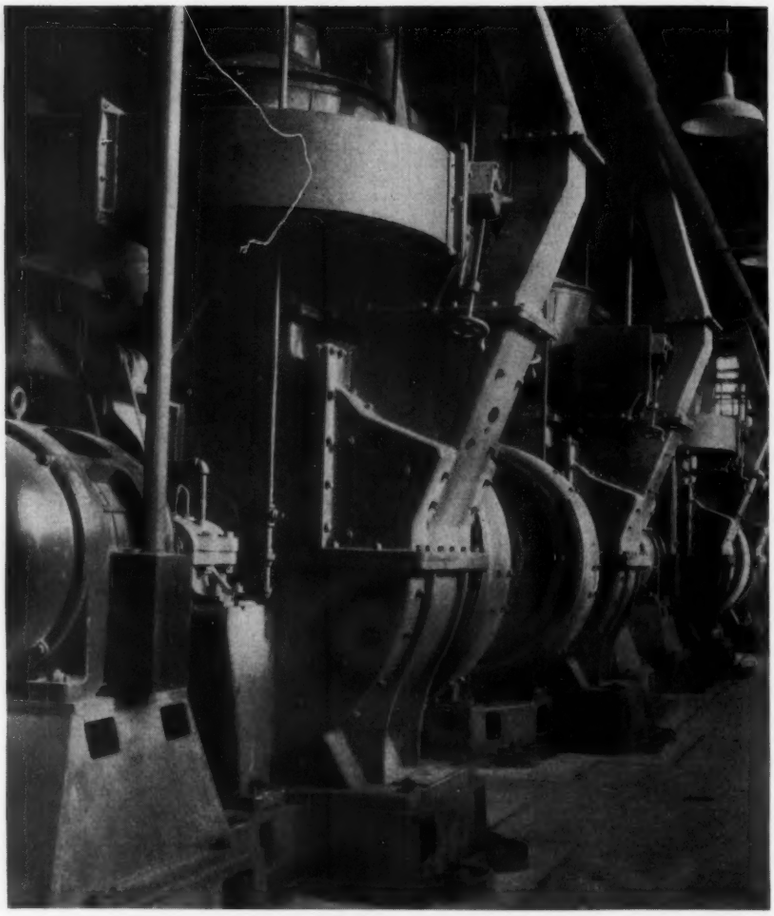
Examination of equation (2) reveals the fact that the term $[1 + 0.00014(t_d - t_w)]$ differs but little from unity at all usual wet bulb depressions. Thus, for a 20 deg wet bulb depression, which is larger than usually obtains in the atmosphere, this term is 1.0028 rather than 1.00. This error is of negligible magnitude in view of the fact that the usual barometer, dry bulb and wet bulb readings do not warrant such accuracy.

Neglecting the bracketed term gives

$$d_m = \frac{B - 0.378\,P_w}{346.5 + 0.7535\,t_d} \text{ lb per cu ft} \qquad (3)$$

Equation (3) is identical in form with equation (1), but P_w is used instead of P_v. Equation (1) is the more exact relation but equation (3) is the practical equation of sufficiently high accuracy for engineering psychrometric computation.

A convenient chart based on equation (3) is shown in the accompanying figure. This chart will prove useful to those engaged in work requiring many determinations of the air density.

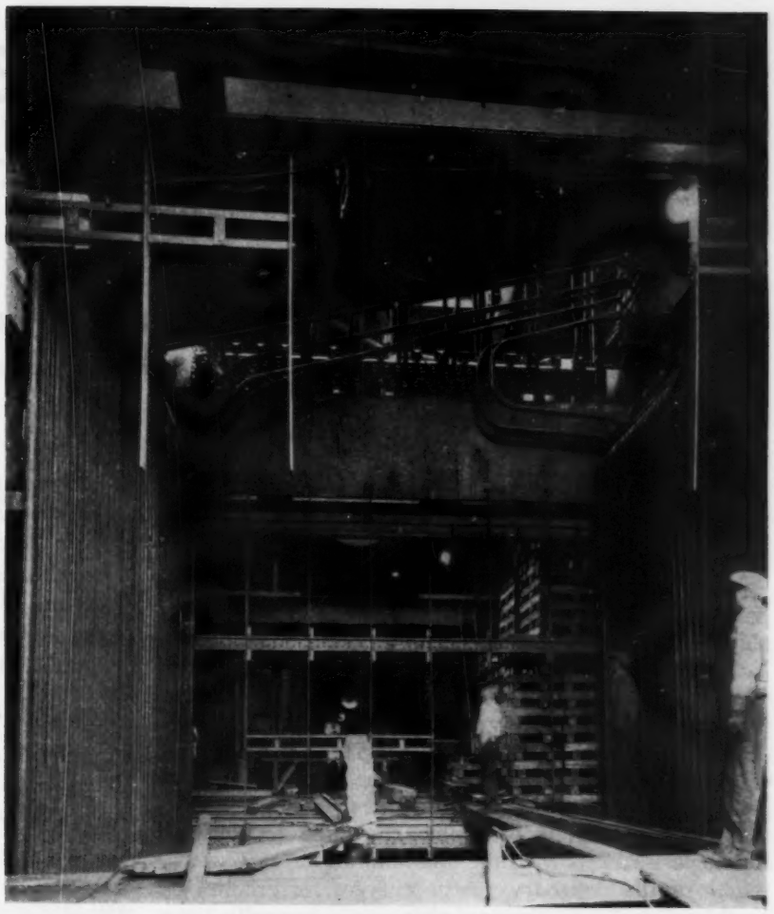


Row of direct-fired pulverizing mills supplying two 140,000 lb per hr boilers at the Newcastle, Ind. plant of the Chrysler Corporation. This installation was completed in record time.

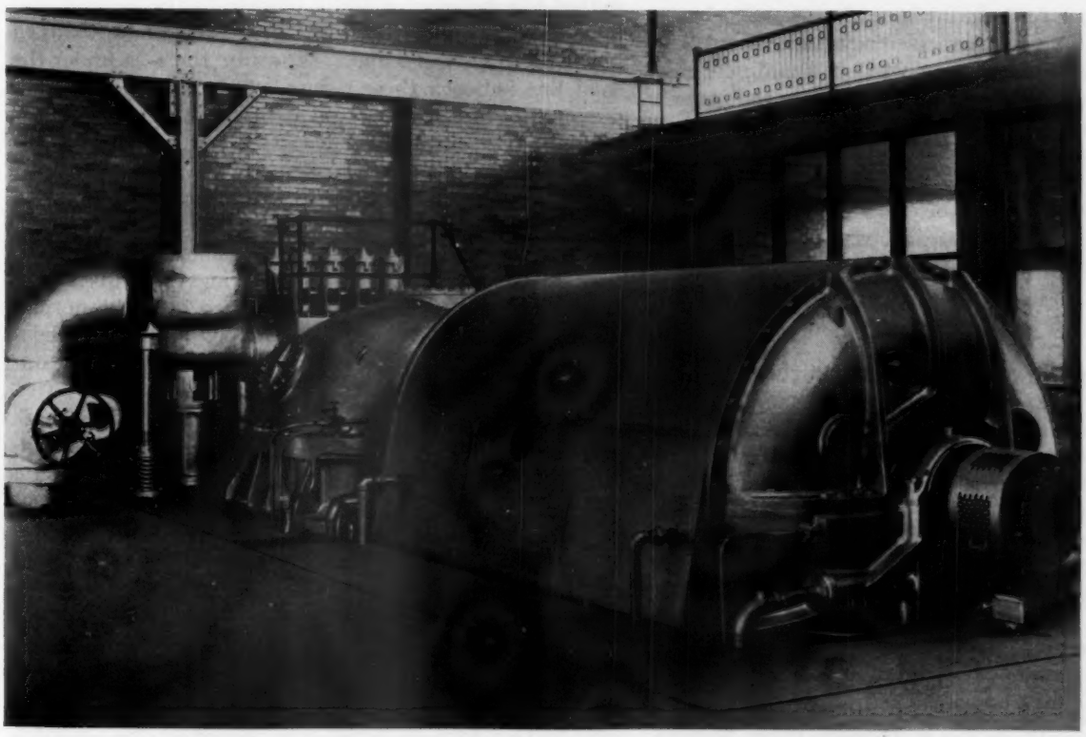
SOME 1934-

Construction view of 1390-lb pressure, 690,000 lb per hr boiler now nearing completion at the Port Washington Station of the Milwaukee Electric Railway and Light Company. This unit will furnish steam to an 80,000-kw turbine-generator.

INSTALLATIONS



Work is progressing on the 1400-lb pressure, 300,000 lb per hr steam generating unit at the Firestone Tire and Rubber Company, Akron. This unit will have a slagging type furnace.



Among activities in the municipal plant field, the City of Richmond, Ind. has lately installed a 15,000-kw 3600 rpm G-E turbine-generator.

Coal Charges for Banking, Lighting and Burning Out Boiler Units*

By GEORGE C. EATON[1]
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This paper deals only with the coal economics of various phases of boiler unit operation. Analyses of the banking, lighting and burning-out phases of operation are described and illustrated. A description of the boiler unit tested and brief explanations of the actual tests, together with carefully detailed discussions of the results and their computation, are given. Curves show the existing conditions and the final results. The paper concludes with comparisons between the results and previously published data.

IT BECAME desirable recently in the steam-electric generating stations of The Edison Electric Illuminating Company of Boston, to have for operating purposes more accurate costs in pounds of coal for various phases of boiler unit operation than were then available. A search of the engineering literature revealed only four sets of data[2,3,4,5] that were at all applicable to the problem at hand. Study of these valuable data indicated that they could not be adapted for use at Boston without questionable extrapolation. Consequently, plans were made to test a boiler unit of average size so that the results might be applied to similar smaller and similar larger units with the minimum of error.

The results desired were the charges (or credits) in pounds of coal over the coal that would normally have been fired during the periods involved.

The overall boiler efficiencies of the type of boiler unit tested had previously been found to be consistently close to eighty per cent during steaming periods, hence it was decided to use this efficiency throughout the computations to determine the coal that would normally be fired to make the steam generated during the periods involved in these determinations.

Preliminary Analysis of Operating Conditions

Before proceeding with the test work, the regular operating conditions were studied with a view to the minimum test work required to obtain the desired results.

Banking Cycle

The banking cycle conditions were roughly as given in Fig. 1. The area under the dotted line ($A + B + D + F$) represents the normal coal that would have been used in a boiler unit operating at eighty per cent efficiency to make the steam generated by the banked boiler unit during the banking cycle. The area under the solid line ($B + C + D + E + F$) represents the coal fired to the banked boiler unit during the banking cycle. The difference ($C + E - A$) between these areas is the coal chargeable to the banking cycle, or the cost of coal for banking the boiler from a to e.

Now it will be noted that the dotted line becomes horizontal at d and remains so to e. The area under the dotted line between d and e represents the normal coal for the steam made from the coal fired to the banked boiler unit between d and e, shown by the area under the solid line between these points. This condition for the purposes outlined below was assumed to exist during the previous portion of the cycle. By this assumption the areas A and B represent the equivalent normal coal extracted from the fuel bed as it was burned down and from the boiler unit setting, etc., and the area D represents the normal coal for the steam made from the coal fired to the banked boiler unit during the bank. The area E represents the excess coal fired over the normal coal F in order to rebuild the fuel bed and restore heat to the boiler unit setting, etc., while raising the steaming rate to its usual value.

The length of the actual bank is in practice a variable length of time dependent on the *steam* demand. Inspection of Fig. 1 shows that if the interval between d and e becomes zero there will be no change in the areas A and B or the area E; but if the interval between a and e becomes less than the interval between a and d, the area B (and possibly A) and the area E will be reduced. Area B (and possibly A) will be less because the unchanging condition existing between d and e are not yet reached and there is still some equivalent normal coal to be extracted from the old fuel bed, the boiler unit setting, etc. Inasmuch as E represents the coal used to rebuild the fuel bed and restore the heat previously removed, it too will be reduced as area B (and possibly A) are reduced. For the purposes of this study

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* A paper presented by the Power and Fuels Divisions at the Annual Meeting of the American Society of Mechanical Engineers, December 3–7, 1934.

[1] Head, Mechanical Technical Engineering Division, Generating Department, The Edison Electric Illuminating Company of Boston.

[2] "Tests of Large Boilers at the Detroit Edison Company" by D. S. Jacobus, New York, New York, A.S.M.E. Transactions, 1911, pages 565 to 638 inclusive.

[3] "Tests of a Type W Stirling Boiler at the Connors Creek Power House of the Detroit Edison Company" by Paul W. Thompson, Detroit, Michigan, A.S.M.E. Transactions 1922, pages 1005 to 1054 inclusive.

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[5] "Proceedings of the National Electric Light Association," page 954, Volume 84, 1927.

the ratio of the sum of the areas A and B to the area E is called the *replacement efficiency* and is assumed to be a constant independent of the length of the time interval between a and e. The use of a constant replacement

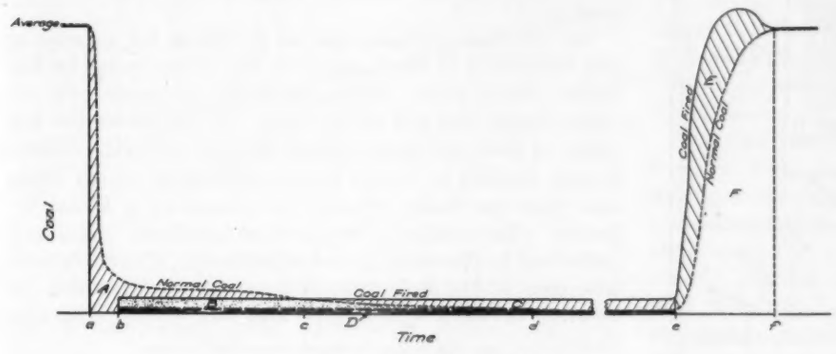


Fig. 1—Banking cycle

efficiency seems logical after studying the factors involved, particularly the rates of heat taken from and delivered to the boiler unit setting. By using this constant ratio, it was possible to calculate the results after determining the quantity E for one length of bank. It would have been impractical to make more than one series of tests.

Starting Cycle

The starting cycle conditions were roughly as given in Fig. 2. The area H under the dotted line represents the normal coal that would have been used in a boiler unit operating at eighty per cent efficiency to make the steam generated during the starting cycle. The area $(G + H)$ under the solid line represents the coal fired to the boiler unit during the cycle. The difference G between these areas is the coal chargeable to the starting cycle and represents the excess coal fired over the normal coal H in order to build up the fuel bed and raise the temperatures of the various parts of the boiler unit to their operating temperatures while bringing the steaming rate to its usual value. From the diagram it will be seen that coal is fired at a rate higher than normal for the better part of the cycle, reducing to normal only shortly before the end. The non-return valve opens at h and the normal coal increases rapidly at first and then gradually reaches its average value simultaneous with the coal fired at i.

Burning Out Cycle

The burning out cycle conditions were roughly as given in Fig. 3. The area $(I + J)$ under the dotted line represents the normal coal that would have been used in a boiler unit operating at eighty per cent efficiency to make the steam generated during the burning out cycle. The area I under the solid line represents the coal fired to the boiler unit during the cycle. The difference J between these areas is the coal creditable to the burning out cycle and represents the equivalent normal coal extracted from the fuel bed as it burned out and from the various parts of the boiler unit while bringing the steaming rate down to zero. From the diagram it will be seen that between j and k the coal fired is maintained at the average rate to fire the coal remaining in the stoker hoppers and at the same time allow a gradual thinning down of the fire with the increased air supply as indicated by the normal coal curve. After the coal remaining in the hopper at j has all been fired at k the normal curve drops rapidly from its maximum at k to zero at l where the non-return valve closed due to loss of pressure in the boiler drum.

With these fundamental considerations in mind the test work was planned and carried out, and the computations for the results given later were made.

Description of Boiler Unit Tested

One of four units at the L Street Station in South Boston was selected. There are eight other boiler units in this station that are fifteen per cent smaller, and three units at Edgar Station in North Weymouth that are thirty-five per cent larger, yet all of similar construction. By the selection of the unit tested, triplication of the tests made was thereby avoided and a considerable monetary saving made.

Fig. 4 shows a cross-section of the L Street unit. Study of this illustration shows the 14,579 sq ft, B & W, straight-tube, sectional-header, cross-drum boiler with integral convection type superheater set above a refractory lined furnace fired by a thirteen-retort, twenty-five-tuyère Taylor stoker of 303.4 sq ft of projected grate area, equipped with double-roll clinker grinder having adjustable aprons. Air is taken from the top of the boiler house where the forced-draft fan is located. A duct leads from this fan to a common trunk duct for all boiler units on the same side of the boiler room. This common duct, however, is sectionalized by tight dampers so that each unit is entirely separate under ordinary conditions, the interconnecting feature being only for emergency purposes. Air under the stoker is controlled by means of fan motor speed and by the dampers shown, a separate control for the extension grate being provided.

The boiler is baffled for three passes of the gases, and the superheater, designed to deliver steam at 566 F at three hundred per cent of boiler rating, is set at the top of the first pass. Gases leaving the boiler flow upward either to the economizer or economizer by-pass.

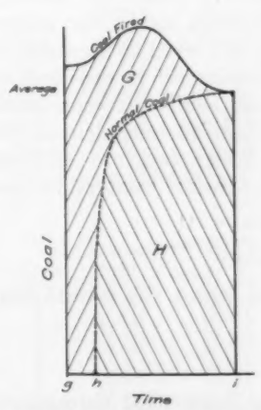


Fig. 2—Starting cycle

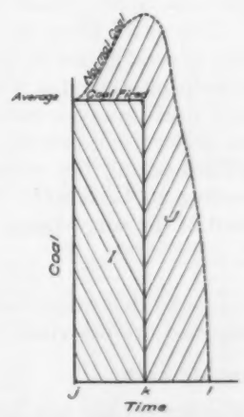


Fig. 3—Burning-out cycle

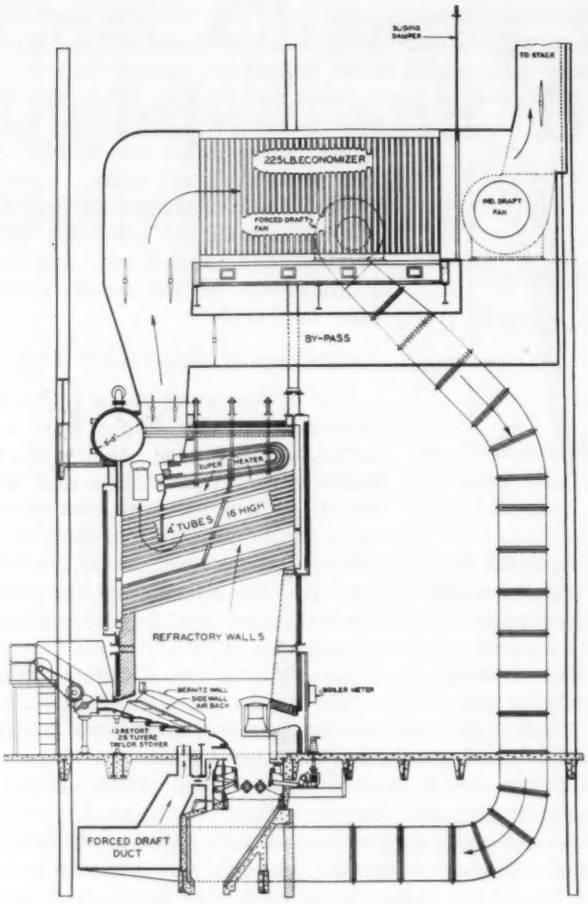


Fig. 4—Cross-section of boiler tested

The portion of the station wherein the twelve three hundred pound boilers are located was laid out and built in three sections from 1916 through 1923. Even at the end of this period steel-tube economizers with deaerators were just being considered, hence the design called for cast-iron economizers with the economizer operating pressure set at approximately 150 lb per sq in. Two sets of feed pumps therefore are used, the first set raising the water from atmospheric pressure in open surge tanks to economizer pressure and the second set from economizer to boiler pressure. The economizer gas by-pass is provided for light load operation, particularly during banking and starting periods when the economizer would steam due to sluggish or intermittent water flow through it. The gases after passing through either the economizer or economizer by-pass are delivered to the stack by the induced-draft fan. The stoker and forced- and induced-draft fans are motor driven, while the economizer and boiler feed pumps are steam turbine driven, the turbines taking the steam at boiler pressure and exhausting to barometric type feedwater heaters located ahead of the surge tanks.

Test Procedure

Tests to determine data from which the results were computed are described below.

Banking Tests

Fundamentally the degree of bank used throughout the tests was a *live bank* or one which maintained the boiler up to the pressure with the non-return valve in the boiler steam lead *open* at all times and the boiler unit ready to carry average load within fifteen minutes. Consequently, the quantity of steam made during the bank had to be determined as well as the quantity of coal fired.

In this station there was no provision for measuring the boiler feed or steam made by the boiler except by the boiler meter which while reasonably accurate over its usual range, was not adequate for the job under the low rates of flow prevalent during banking periods. Hence it was decided to install temporarily small weigh tanks and feed the boiler directly by means of a steam injector. The coal was weighed on platform scales and delivered to the stoker in wheelbarrows. Counters were also used on the stoker ram drive shafts to determine the relation between weight fired and ram strokes and as a check.

Two types of banking tests were run, namely,

(*a*) *Long bank* tests of 40 to 65 hr duration covering the period in Fig. 1 from *a* to *e*.

(*b*) *In from* (bank) tests after the boiler had been banked for approximately seven hours. The *in from* (bank) tests covered the period *e* to *f* in Fig. 1.

When the forced- and induced-draft fans were stopped and the sectionalizing damper in the common trunk forced-draft duct positively blocked to prevent any possible air leakage under the abnormal conditions existent during the run, a long bank test was started. The stoker hopper was leveled at this time and at each hour thereafter during the test. As soon as the evaporation was reduced to the capacity of the injector and weigh tanks, the boiler feed pump was stopped and the injector started. The evaporation before starting the injector was taken from the boiler meter. The long bank tests ended when the fans were started after leveling the stoker hopper. Observations were made as listed in Table I at fifteen-minute intervals.

When the forced- and induced-draft fans were started after a short bank of approximately seven hours, an *in from* (bank) test was begun. The evaporation was measured entirely by the boiler meter as the rate of steaming was soon above the capacity of the injector and weigh tanks. The coal was measured by using the counters mounted on the stoker drive shafts. Very

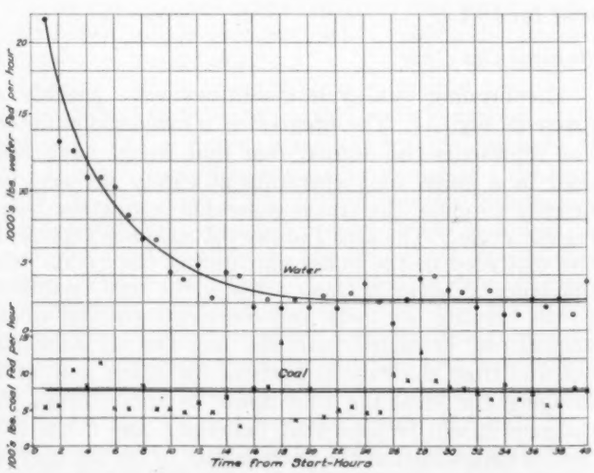


Fig. 5—Long-bank tests; coal fired and water fed

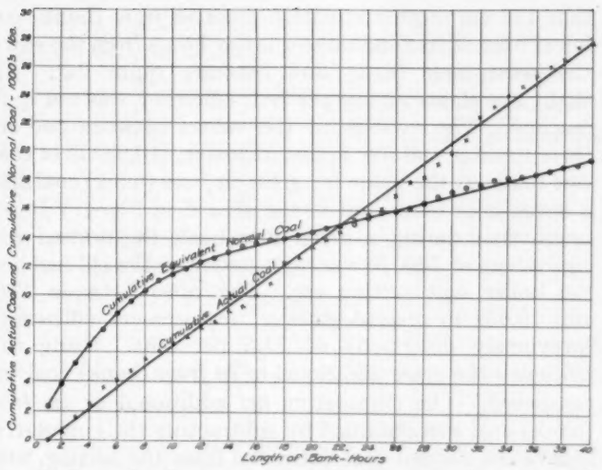

Cumulative Actual Coal and Cumulative Normal Coal - 1000's lbs.
Cumulative Equivalent Normal Coal
Cumulative Actual Coal
Length of Bank-Hours

Fig. 6—Long-bank tests; cumulative actual coal and cumulative equivalent normal coal

consistent relations between weighed coal and stoker ram strokes were obtained during the long bank tests. The use of these relations allowed the labor involved in making these tests to be materially reduced. These tests were each continued for approximately five hours after which time it was found that the expected normal (eighty per cent) efficiency of the unit was reached. Observations were made at fifteen minute intervals.

Starting Tests

When the stoker was started and the wood fire ignited a test was started. The coal fired was measured by the ram strokes and the evaporation after the opening of the non-return valve was recorded from the boiler meter. Observations were made at fifteen-minute intervals. A test was continued for about three hours after the boiler unit had reached its normal rate of steaming to allow conditions in the fuel bed and other parts of the boiler unit to become stable.

Burning-Out Tests

With the stoker hopper levelled, a test was started. The coal fed was measured by the ram strokes and the evaporation before the closing of the non-return valve was recorded from the boiler meter. Observations were made at fifteen minute intervals. A test was continued until the non-return valve was closed.

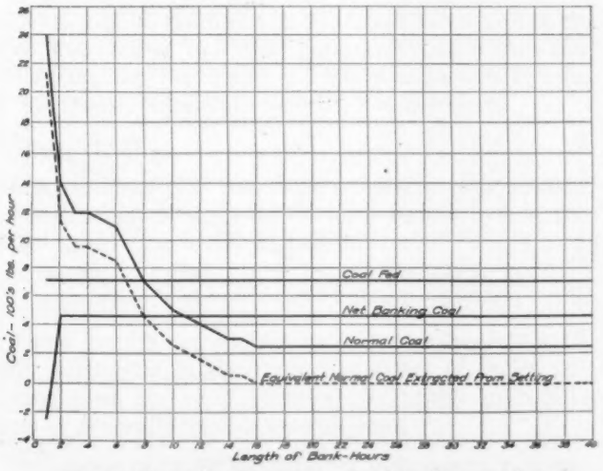


Fig. 7—Long-bank tests; actual and normal coal

Computation of Results

Long Banking Tests

The average of the weights of water fed to the boiler were computed on an hourly basis and plotted in Fig. 5. The weight of injector waste was first subtracted from the gross water fed. No correction for the boiler steam in this injector waste was made as it was found that the error involved was less than the expected accuracy of the tests.

The data for the first hour was taken by inspection from a large number of boiler meter charts. The averages of steam pressure, steam temperature with stem correction and feed temperature were computed. From these data the average Btu per pound absorbed was found. As discussed above, an efficiency of eighty per cent was used to compute the equivalent normal coal required to generate this steam. Coal containing 14,050 Btu per pound as fired was burned during these tests. The equivalent normal coal was made cumulative and plotted in Fig. 6. A smooth curve was drawn through these points as indicated and an average hourly normal coal obtained by differences from this curve as shown in

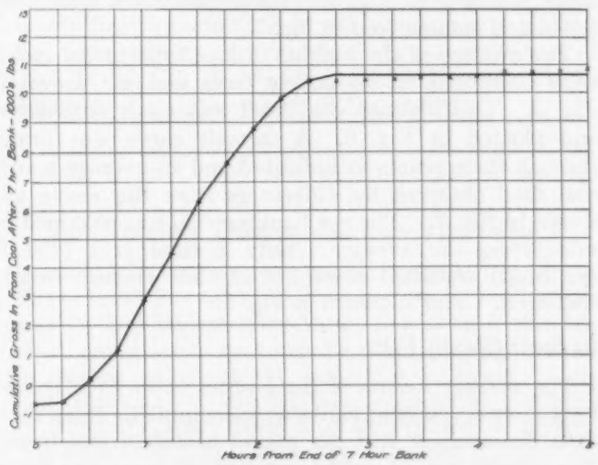


Fig. 8—In from (bank) tests; cumulative gross in from (bank) coal

Fig. 7. It will be noted that after the sixteenth hour equilibrium conditions were reached. The differences between the earlier hour values and this constant figure

STARTING TESTS

Test No.	Normal Coal Pounds	Coal Fired Pounds	Coal Heating Value Btu/Lb (as Fired)	Net Charge Actual Coal Pounds	Net Charge Standard* Coal Pounds
1	31,517	51,552	14,271	20,035	20,330
2	26,762	49,073	14,336	22,311	22,740
3	35,199	63,353	14,313	28,154	28,650
4	38,925	58,105	14,251	19,180	19,430
5	27,722	52,035	14,237	24,313	24,610
6	35,289	57,541	14,243	22,252	22,530
Average	32,569	55,276	14,275	22,708	23,050

* Same as banking cycle tests—14,050 Btu per lb. as fired.

BURN OUT TESTS

Test No.	Normal Coal Pounds	Coal Fired Pounds	Btu/Lb (as Fired)	Net Charge Actual Coal Pounds	Net Charge Standard* Coal Pounds
1	39,544	18,200	14,271	21,344	21,660
2	37,815	16,813	14,336	21,002	21,410
3	31,421	20,106	14,237	11,315	11,450
4	36,639	20,793	14,290	15,846	16,100
5	31,131	19,414	14,290	11,717	11,920
6	36,602	18,721	14,251	17,781	18,020
7	37,226	21,660	14,237	15,566	15,760
Average	35,768	19,387	14,273	16,367	16,620

* Same as banking cycle tests—14,050 Btu per lb. as fired.

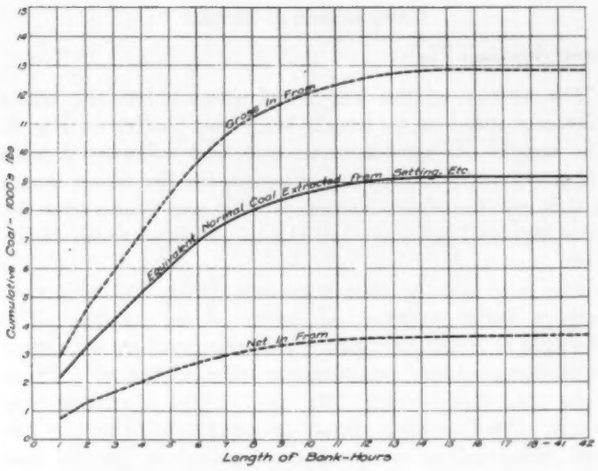

Gross In From
Equivalent Normal Coal Extracted from Setting, Etc.
Net In From
Cumulative Coal - 1000's lbs
Length of Bank-Hours

Fig. 9—Banking tests; cumulative in from (bank) coal

(the average ordinate of the area *D* in Fig. 1) was the equivalent normal coal extracted from the old fuel bed, the boiler unit setting, etc., for the individual hours. The summation of these differences is the sum of the areas *A* and *B* in Fig. 1. These differences were computed and summarized in Fig. 7.

The average of the weights of coal fired to the stoker were computed on an hourly basis and are shown in Fig. 5. This average coal fired was made cumulative and plotted in Fig. 6. A smooth curve was drawn through these points as indicated and an average hourly coal fired obtained by differences from this curve and shown in Fig. 7. The net banking coal was obtained by subtracting the average hourly normal coal (250 lb per hour) obtained above from this average hourly coal fired. This is shown in Fig. 7.

In From (Bank) Tests

The average results of three series of *in from* (bank) tests after seven-hour banks were computed. From these data the average Btu per pound absorbed was found. The normal coal at eighty per cent efficiency was found similarly to that in the long bank tests. The gross *in from* (bank) coal was found cumulatively by taking the difference between the cumulative actual coal and the cumulative normal coal at eighty per cent efficiency. The differences are plotted in Fig. 8. It will be noted that the curve of cumulative gross *in from* (bank) coal knees over at two and three-quarter hours from the end of the seven-hour bank, and becomes quite flat. The slight rise shows eighty per cent efficiency was not quite reached. The average of the values between two and three quarter and five hours, inclusive, (10,632 lb of coal) was taken as the value for gross *in from* (bank) coal after a seven-hour bank and is the area *E* in Fig. 1. It was found that during a seven-hour bank the normal coal equivalent of 7600 lb was extracted from the old fuel bed, the boiler unit setting etc. The ratio between 7600 and 10,632 lb of coal gives a "replacement efficiency" (previously described) of 71.5 per cent. Using this efficiency the gross additional or *in from* (bank) coal was computed. The cumulative *net* additional or *in from* (bank) coal was obtained by subtracting the cumulative equivalent normal coal extracted from the setting, etc., from the cumulative gross *in from* (bank) coal. This is shown in Fig. 9.

The hourly charges for the banking cycle in pounds per hour of actual bank were obtained by dividing the cumulative net additional or *in from* (bank) coal by the length of actual bank and adding the result to the net banking coal. These charges are shown in Fig. 10. The total charges for the banking cycle for banks of various lengths were obtained by multiplying the hourly charge by the length of bank. These total charges are shown in Fig. 11.

Starting and Burn-out Tests

Due to the difference in conditions found between the six and seven tests respectively in the two series of tests, it proved necessary to compute each test of each series separately. The normal coal at eighty per cent efficiency was computed similarly to that in the long bank tests. The tables show the combinations of the results of the two series of tests together with the heating values as fired of the coal used and the corrections of the net charge and credit from the actual to the standard coal as found in the banking cycle tests.

Results

(*a*) Banking charges for banks over various periods of time—See Figs. 10, 11 and 12.

(*b*) Lighting charge—23,050 lb total, or 76.0 lb per sq ft of projected grate area.

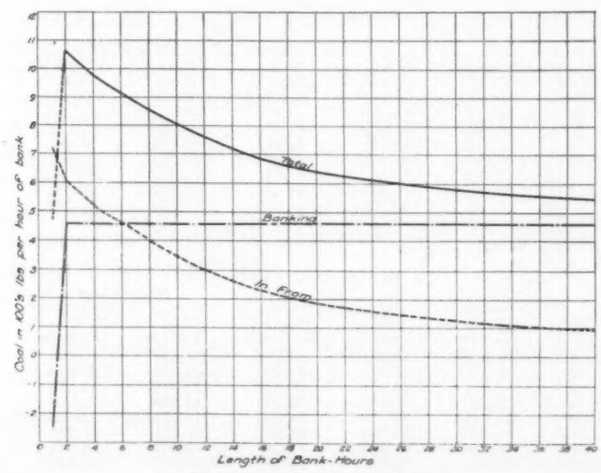


Fig. 10—Banking charges

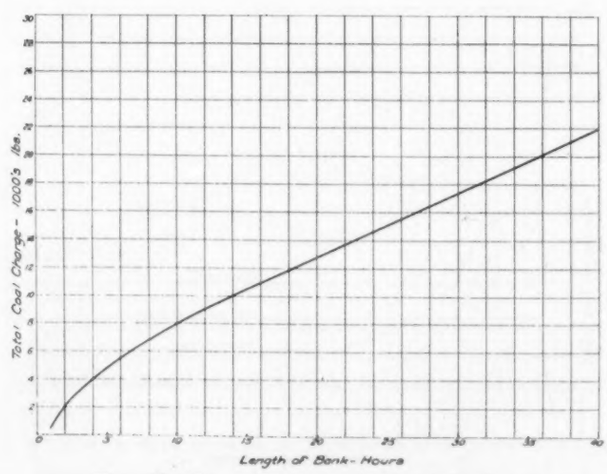


Fig. 11—Cumulative banking charges

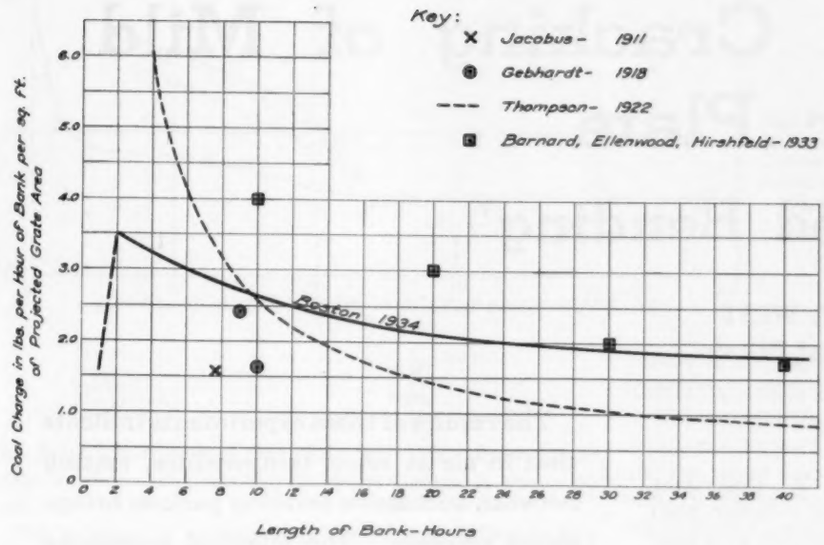

Key:
Jacobus - 1911
Gebhardt - 1918
Thompson - 1922
Barnard, Ellenwood, Hirshfeld - 1933
Boston 1934
Coal Charge in lbs. per Hour of Bank per sq. Ft. of Projected Grate Area
Length of Bank-Hours

Fig. 12—Banking charges compared

(*c*) Burn-out credit—16,620 lb total, or 54.8 lb per sq ft of projected grate area.

Comparisons with Other Published Data

Banking Tests

The results of these tests are compared in Fig. 12 with other data[2,3,4,6] as indicated. It will be seen that the tests at Boston fall close to those published prior to the publication of Messrs. Barnard, Ellenwood & Hirshfeld's data in 1933, which data lie above those presented in this paper. It would seem, therefore, that the data herein given may be generally applicable to stoker-fired boiler units with refractory-lined furnaces.

Lighting Tests

The result of this test work compares with another[3] in terms of pounds of coal fired per square foot of projected grate area, as follows:

Thompson	1922	82 lb per sq ft
Boston	1934	76 lb per sq ft

and with others[3,6] in terms of pounds of coal fired per boiler horsepower, as follows:

Boston	1934	15.8 lb per bhp
Thompson	1922	12.9 lb per bhp
N.E.L.A.	1927	10.7 lb per bhp

It will be observed from this comparison that on one basis the results given in this paper fall below and on the other basis above the other published values, thus substantiating the previously published data and forming an apparently excellent basis for use elsewhere.

Burn-out Tests

The result of this test work compares with another[3] in terms of pounds of coal fired per square foot of projected grate area basis, as follows:

Boston	1934	54.8 lb per sq ft
Thompson	1922	40.3 lb per sq ft

These results are in fair agreement considering the wide differences in the respective types of boiler unit construction, and seem, therefore, adaptable to installations of generally similar construction.

[6] "Elements of Heat-Power Engineering" by W. N. Barnard, F. O. Ellenwood and C. F. Hirshfeld, page 606, Part II.

Acknowledgments

The author wishes to take this opportunity to extend his thanks to Messrs. R. E. Dillon, R. Brown and W. E. Kennedy for their kind aid in the planning and making of the tests, and to express his sincere appreciation of the aid of Mr. H. E. Stickle and the late Mr. H. L. Goodwin in the computation of the results.

To Advise Power Show Visitors

As an added feature to this year's National Exposition of Power and Mechanical Engineering, to be held at the Grand Central Palace, New York, Dec. 3 to 8, the Advisory Committee has arranged an Engineering Conference Bureau in Booth 51, near the entrance. Here visitors can come to discuss their engineering problems with engineers apart from the atmosphere of selling. At the booth there will be on duty at all times engineers qualified to discuss intelligently power problems with visitors and to explain the use of a large Power Loss Check Chart arranged to systematically survey all possible losses that may prevail in or about a power plant.

Court Test of Government's Power Policy Likely

Determined opposition to the Government's power policy, as recently expressed by the President, is indicated along legal lines by the Edison Electric Institute. Opinions have been obtained, by President T. N. McCarter of the Institute from Newton D. Baker, former Secretary of War and James M. Beck, former Solicitor General both declaring that the T. V. A. legislation is unconstitutional. It would appear, therefore, that court action is imminent. At a recent meeting of the trustees of the Institute it was resolved that the executive committee be empowered to take any necessary steps in behalf of an early determination of the powers of government and the rights of investors as to competitive projects initiated by the government, and to employ such counsel, engineers and economists as may be necessary to this end.

Accelerated Cracking of Mild Steel Boiler Plate under Repeated Bending*

By C. H. M. JENKINS and W. J. WEST
National Physical Laboratory, Great Britain

The results of these experiments indicate that in air at room temperature, resting between successive bending periods brings about recovery. The effect of increasing the temperature was a reduction in the number of bends required to produce fracture, but there was no appreciable difference at 100 C between bending in air, tap water or caustic soda solution.

IN THE series of tests by the late Dr. W. Rosenhain, and A. J. Murphy,[1] bars cut from a boiler plate steel and from a cold-rolled mild steel strip were bent in alternate directions while immersed in various media such as air, tap water, brine and sodium hydrate solution. The bars were bent at regular intervals by a load which produced a permanent set in the material. The endurance of the samples (expressed as the number of deflections required to produce rupture) was determined. The greatest reduction in the number of alternations from the standard number based on air tests at atmospheric temperature was noted in the case of specimens bent in tap water. These tests required 37 per cent fewer bends than had been required in the air tests. Full reduction in the number of alternations was noted when the interval between successive bends was 24 hr. The earlier experiments did not show that there was any evidence of intercrystalline fracture, whether specimens were ruptured in air, tap water or caustic soda. A similar absence of evidence is recorded in the present paper, although some tests have been made using longer periods of exposure to corrosive attack by reducing the deflection given to the specimens.

Present Work

The present work is confined, first, to further tests at room temperature, and, secondly, to an examination of similarly bent specimens at higher temperatures, namely, 100 C and in air at 200 C.

It is apparent that the degree of flexure likely to occur in a boiler is of a very much smaller order than that imposed on the present test specimens. It should be noted that in a boiler the working stress is superimposed upon that resulting from the flexure in such a manner that there is a tendency to open up incipient cracks, and that during the operation of a boiler the higher temperatures and pressures may influence the nature of the corrosive action. The flexure referred to may occur close to heavily reinforced seams, and local deformation may take place in the neighborhood of rivet holes either during assembly or in subsequent boiler operation.

In the present series of experiments two forms of bend test-pieces were adopted. The first was similar to that used in the previous experiments and the second was developed so that microscopic examination of the surface of the bent specimens could be made. In all tests the specimens were bent with their minimum dimensions forming the depth of the beam. Particulars of the specimens follow:

(1) A simple rectangular test-piece which was subjected to three-point loading from a central plunger. The dimensions of the specimens were 8 × 0.75 × 0.50 in. and they were supported on "stay-brite" cylinders spaced 15 cm apart. The deflection applied bent the specimen from a position 1 cm on one side of the center line to a reverse position 1 cm on the other side of the center line.

(2) In some of the tests now described, other specimens were subjected to bending under four-point loading applied by a centrally situated plunger having cylindrical contacts whose centers were spaced 3 cm apart. The radius of curvature of the face of these two cylindrical contacts was 1.5 cm. The test specimens were of the same length as those of the three-point type, but were 20 × 12.5 mm in cross-section. In some of the tests with these specimens the central portion was reduced between the two contact surfaces of the ram. Both sides of these test specimens were finished by grinding and polishing. This reduction in cross-section caused the stress set up during bending to be concentrated on the upper and lower surfaces at the center of the reduced portion of the specimens.

Exposure to the various media at 100 C was carried out in steel tubes containing the liquid heated by a water bath.

Chemical Analysis of the Boiler Plate (EA Material)

The composition of the material used in the tests was as follows:

* From a paper presented at the Luxembourg Meeting of the Iron and Steel Institute.
[1] *Journal of the Iron and Steel Institute*, 1931, No. I, p. 259.

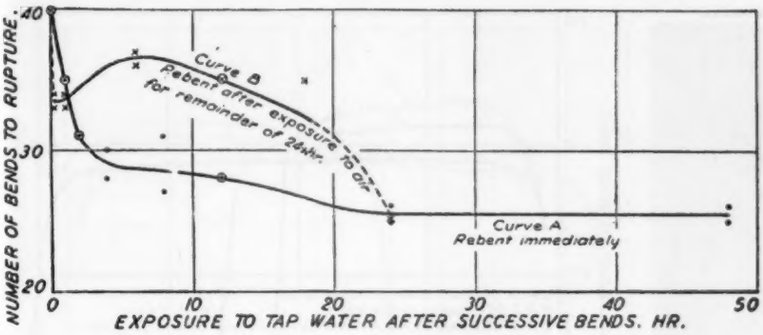


Fig. 1—Specimens bent in tap water. Curve A: No exposure to air between successive bends. Curve B: Bent regularly every 24 hr, removed from tap water after interval shown, and exposed to air for remainder of 24-hr cycle

Carbon	0.11	per cent
Silicon	0.10	"
Sulphur	0.444	"
Phosphorus	0.035	"
Manganese	0.52	"

The Brinell hardness of this plate was 110. Four specimens, marked *EB*, from a plate of the same cast were also used.

The solution of caustic soda containing 500 grm per liter was prepared from chemically pure sticks of sodium hydroxide.

In the earlier tests the behavior of the specimens tested in brine was similar to those tested in tap water. No further tests therefore were made in sodium chloride solutions.

In all cases throughout the present work the specimens which had been exposed to water were dried by immersion in a high-grade denatured alcohol before exposure to air.

When the single-contact plunger was used, about 40 reversals were given to the specimens to cause rupture in air at room temperature. This number does not change even if the period of resting between successive bends is increased from 0 to 24 hr.

In general, the specimens showed signs of initial cracking when between one-half and three-quarters of the number of bends had been applied.

Bend Tests at Room Temperature

Influence of Time. In this series of tests, the specimens were bent in tap water and held in that medium for the duration of the exposure period. The specimens were not brought into air but were kept continuously under the surface of the water in an open-top tank.

The experimental data relating to specimens which had been bent every 1, 2, 4, 8, 12, 24 and 48 hr are plotted in curve *A* of Fig. 1. The values plotted at zero time of this curve relate to specimens bent continuously in the tensile testing machine. The curve shows that a period of exposure between successive bends markedly lowers the resistance of the bars.

The curve indicates that the further decrease in the resistance beyond 4 hr is only slight. Confirmation of the course of this curve has been obtained from the results of specimens loaded by the four-point plunger. In those tests a similarly rapid fall and change in the direction of the curve after an exposure to water of from 2 to 4 hr was obtained, but the agreement between duplicate tests was not sufficiently good to warrant the inclusion of numerical data in the paper.

Influence of Intermittent Exposure to Air and Water

In these tests the specimens were bent either in air or in water. In all cases where exposure was required, they were given, immediately following the bending, the desired period of exposure in the same medium. Fig. 2 relates to specimens bent in air at room temperature, and indicates the general decrease in the number of bends before fracture occurs, after immersion in tap water for increasing periods of time between successive bends. It will be noticed that there is a sudden fall equivalent to six bends if specimens exposed to a 24-hr corrosion period in air are bent in water instead of in air.

The choice of a cycle of operations of 24 hr is, of course, arbitrary; it is likely that somewhat different results would have been obtained if a longer or shorter period had been selected.

The data given in Fig. 3 are the converse of those given in Fig. 2, in that the specimens were now bent in water instead of in air. The data show that there is a reduction of seven in the number of bends, if instead of the specimens being wholly maintained in air they are just placed in water for bending. A noticeable feature in this curve is the indication of the rise in resistance after the sudden initial fall, brought about by bending in water. This suggests a recovery of the specimens on their being allowed to stand in water. This recovery is followed by a

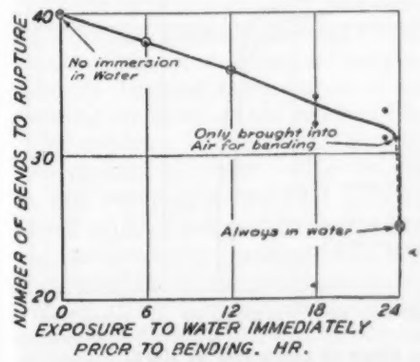


Fig.2—Specimens bent every 24 hr in air

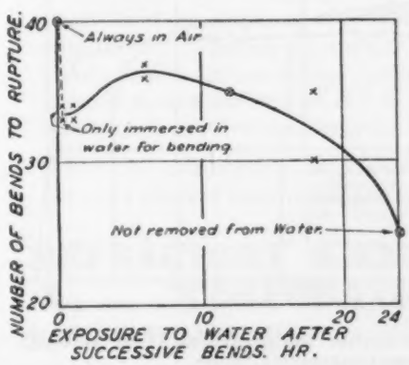


Fig.3—Specimens bent every 24 hr in tap water. Specimens were removed from water after the interval shown and exposed to air for the remainder of the 24-hr cycle

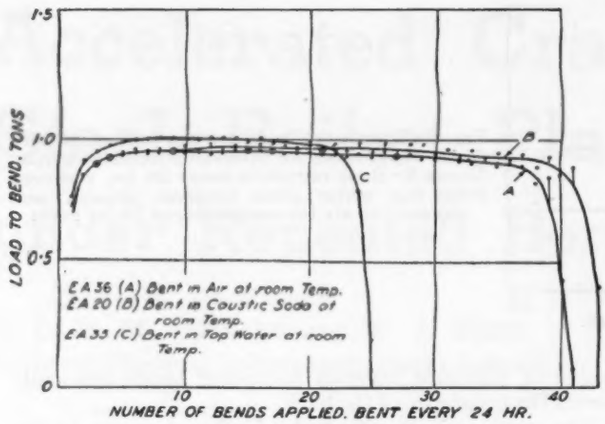


Fig. 4—Comparative effect of bending and exposure to various media at room temperature

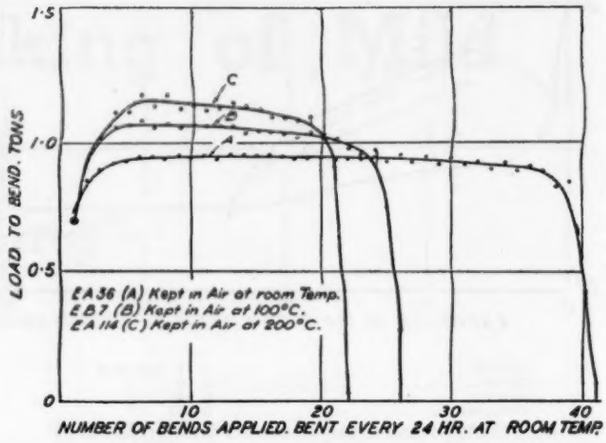


Fig. 5—The effect of higher temperatures (24-hr periods) between successive bends

gradual fall in the total number of bends if greater exposure to water is given.

For equal periods of exposure to air or to water (12 hr in each medium) there is no great difference between the resistances of specimens bent in air and of those bent in water.

Curves *A* and *B* of Fig. 1 indicate the recovery brought about by exposure to air between successive bends. It should be noted in the upper curve *B* that in the experiments there was not a constant time of exposure to air but a decreasing time which became zero when the curve terminated at 24 hr. In the case of curve *A*, however, the specimens were bent and the exposure to water was continued until the time for rebending had occurred.

Further Bend Tests in Various Media

Figs. 4 to 8 show curves plotted from typical data obtained during the experimental work. In general they indicate that the load required for bending rises rapidly to a maximum value soon after the first few bends, and falls off rapidly just before rupture.

Fig. 4 indicates the effect of bending and maintaining specimens in various media. In the case of *EA*36 (curve *A*) bending was carried out in air. A similar degree of resistance was shown by the specimen bent in caustic soda at room temperature (*EA*20, curve *B*), but a greatly diminished degree of bending is revealed in tap water at room temperature, as is indicated by the shortened life of the specimen *EA*35 (see curve *C*).

Fig. 5 relates to specimens bent every 24 hr after being maintained in air at room temperature, 100 C and 200 C. It is clear that the increase of temperature has a marked stiffening effect on the properties of the steel in that an increased load is required to bend them. There is a marked reduction in the number of bends required to produce fracture, but the effect of the aging treatment between the bends causes a reduction in the number of bends which can be applied, that is, a longer period of exposure at 100 C weakens the material according to these tests. The data for resting periods of 24 and 1 hr are given in the two curves marked *B* in Figs. 5 and 6. It will be noticed that in these figures both curves marked *A* and both marked *C* are similar.

Fig. 7 shows the effect of bending in tap water at 100 C and at room temperature, and in air at 100 C. There is no great difference between these curves, but a comparison with Figs. 5 and 6 indicates the marked reduction from the results of the air test. From the data given in Fig. 7 the conclusion has been drawn that tap water does not further diminish the flexibility at 100 C. It is probable that at 100 C little air is retained in the tap water, so that the preferential attack by tap water may be confined to lower temperatures.

Fig. 8 indicates the effect of bending specimens in caustic soda at room temperature and at 100 C, together

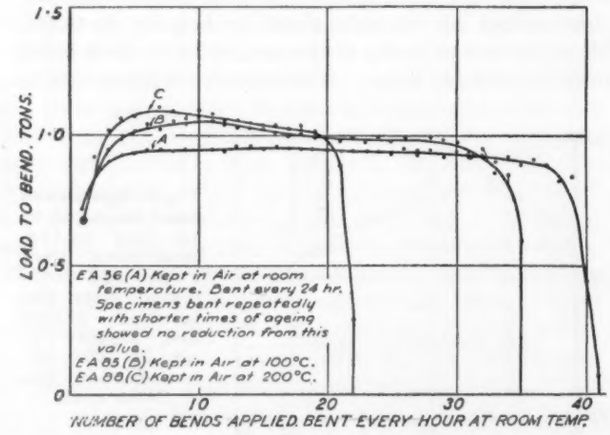

LOAD TO BEND. TONS.
1·5
1·0
0·5
0
A
B
C
EA 36 (A) Kept in Air at room temperature. Bent every 24 hr. Specimens bent repeatedly with shorter times of ageing showed no reduction from this value.
EA 85 (B) Kept in Air at 100°C.
EA 88 (C) Kept in Air at 200°C.
10
20
30
40
NUMBER OF BENDS APPLIED. BENT EVERY HOUR AT ROOM TEMP.

Fig. 6—The effect of higher temperatures (1-hr periods) between successive bends

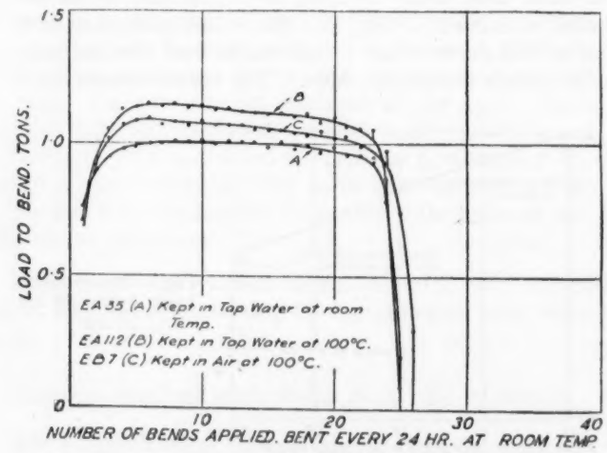


Fig. 7—The effect of tap water at 100 C

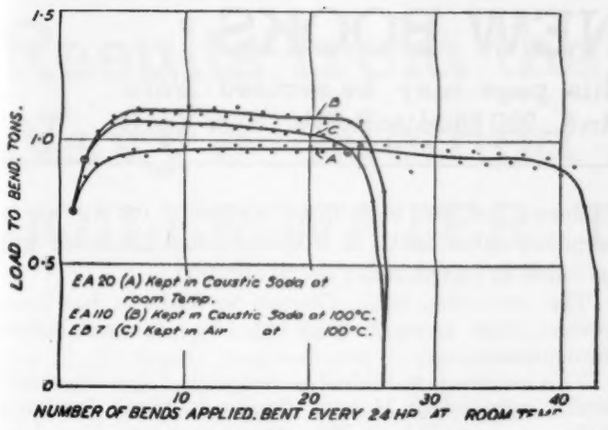


Fig. 8—The effect of caustic soda

with a comparison specimen bent in air at 100 C. From the numerical values derived from these experiments it might reasonably be possible to deduce that the results in caustic soda conform to those obtained by tests made in air. During the course of these experiments, however, it was noticed that the specimens blackened from a surface corrosion effect which differed in its mechanism of formation from ordinary rusting.

In order to indicate the effect of prolonged preliminary low-temperature heat treatment, two specimens were exposed for 30 days at 100 C to caustic soda solution and two at a similar temperature in air. At the end of this period they were bent repeatedly in air without further aging until rupture occurred. There was little difference in the numerical results. These results indicate that there is no reduction due to surface or depth attack by caustic soda.

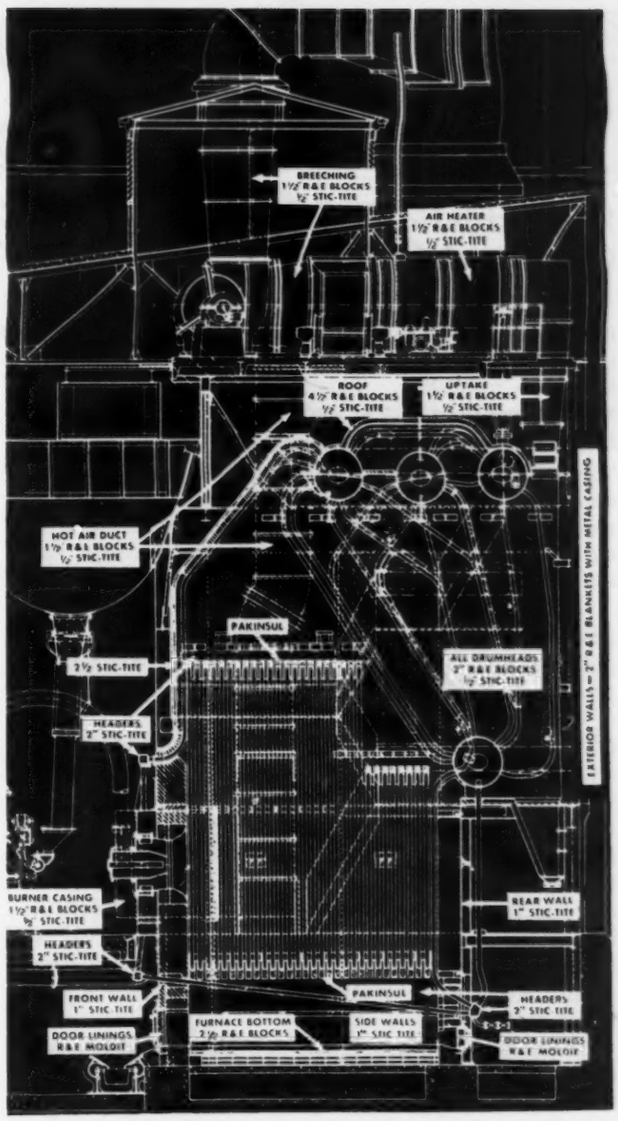
It appears that the bending experiments in caustic soda did not result in the production of intercrystalline cracking which is characteristic of the defect commonly referred to as "caustic embrittlement."

Conclusions

The results of the experiments indicate that, at air temperature, resting between successive bending and corroding periods brings about a recovery in the number of deflections.

The effect of increasing the temperature of testing leads to a general reduction in the number of bends required to produce fracture, but there is no appreciable difference in the numerical values of experiments at 100 C if the bending is in air, tap water or caustic soda solution, although in the latter reagent the type of corrosion is not similar to that occurring in tap water. In all cases the reduction in the number of deflections is about equal to that formerly noted as a result of 24 hr exposure to tap water at atmospheric temperature. The conditions of bending have not been such as to produce "caustic cracking" in the caustic soda solutions.

No evidence was obtained that a voluminous corrosion product is formed within the cracks. Experiments in tap water indicated that a loose flocculent deposit of red oxide of iron was formed in the solution surrounding the specimen; probably this deposit was an oxidation product of ferrous hydroxide. Tests in caustic soda at 100 C showed that the surface of specimens became coated with a black oxide of iron which was strongly magnetic.



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REVIEW OF NEW BOOKS

Any of the books reviewed on this page may be secured from Combustion Publishing Company, Inc., 200 Madison Ave., New York

Specifications and Tests for Coal and Coke

For the first time, a compilation of all the standard and tentative specifications and tests for coal and coke, as issued by the American Society for Testing Materials, has been published. This includes five specifications, thirteen methods of test and the standard definitions of terms relating to coal and coke.

Foundry coke and gas and coking coals are covered by specifications—and to make the pamphlet complete, the recently approved requirements for classification of coal by rank and by grade, developed by the Sectional Committee on Classification of Coals, are included.

One of the important activities of A.S.T.M. Committee D-5 on Coal and Coke, which is sponsor for the publication, is the development of satisfaction sampling procedures. In this compilation are given the methods of laboratory sampling and analysis of coal and coke, and procedure for sampling coal; also sampling coke for analysis.

The standard tests for the cubic foot weight of coke and of crushed bituminous coal are included, as well as the methods of sieve analysis of these products, and tests for the fineness of powdered coal. The shatter and tumbler tests for coke are detailed; also the method of determining volume of cell space of lump coke and testing for size of anthracite. An important test for the agglutinating value of coal, issued in the form of a proposed draft, is given.

The publication aggregates 108 pages in heavy paper cover. Price $1.00.

Mathematical Tables

Compiled from the Handbook of Chemistry and Physics

By Charles D. Hodgman

This is the third edition of the collection of mathematical tables and formulae which, although different in form, is identical in content with the mathematical section of the 18th edition of the Handbook of Chemistry and Physics. In this new volume all of the numerical tables have again been completely and carefully checked; the few minor errors found have been corrected.

Among the tables and formulae contained in this book are the following: Algebraic Formulae; Mensuration Formulae; Trigonometrical Functions in a Right-Angled Triangle; Relations Between Sides and Angles of Any Triangle; Differentials; Integrals; Analytical Geometry; Four-Place Logarithms; Five-Place Logarithms; Hyperbolic Functions; Degrees, Minutes and Seconds to Radians; Degrees and Decimals to Radians; Decimal Equivalents of Common Fractions; Numerical Constants; Logarithmic Constants; Interest Tables.

One new table—Factors and Primes—has been added. This covers eight pages, giving the factors of factorable numbers and the logarithms of primes for all whole numbers up to 2000. It is believed that this table will be found an exceptionally useful addition.

The conversion table, Degrees to Radians, has been revised, now being extended to five decimal places throughout.

This volume is published in two sizes. The desk size, which is bound in Marcon, flexible fabricoid, contains 237 pages, size $5^1/_4 \times 7^3/_4$; the pocket size, bound in green leatherette, contains 237 pages, size $4^1/_8 \times 6^5/_8$. Prices $1.50 and $1.00 respectively.

The Engine Indicator

Its Design, Theory and Special Applications

By K. J. DeJurasz

The Engine Indicator by K. J. DeJurasz, Assistant Professor of Engineering Research at The Pennsylvania State College, presents the history, theory and construction of the many forms of the pressure indicator from its inception to the present day. It contains much valuable information not only for engineers in power plants, pumping stations, engine factories and automotive and aeronautical research laboratories but also for all engineers who have to investigate *forces* and *motions*, and particularly for engineers who may not be principally interested in engines but who are concerned with *variable pressures*.

The material in this book has, to a great extent, appeared in installments in the magazine *Instruments*. For publication in book form, however, the material has been revised, errors eliminated, the description of a number of recent instruments added and supplemented by an extensive chapter on the theory of the indicator.

This book contains 235 pages, size $5^1/_2 \times 8^1/_2$, and is very well illustrated. Price $3.75, including a year's subscription to *Instruments*.

Diesel Engineering Handbook

Edited by L. H. Morrison and T. A. Burdick

This is the seventh edition of this handbook which brings the reader up to date on diesel practice in this country as pertaining to stationary practice, automotive and railway applications. Following a basic discussion of the diesel cycle, the principal types and makes of engines are described, and chapters are devoted to various auxiliaries, to lubrication, cooling, installation and starting. Maintenance and inspection schedules are included, as well as a set of station logs for keeping plant records.

The book is both educational and informative and should prove of great assistance to men operating diesel plants or steam plants that include supplementary diesel service.

The volume contains 320 pages, 9 × 12 in., cloth binding and fully illustrated. Price $5.00.

Results from the Change in the Navy's Method of BOILER-WATER TREATMENT*

By ROBERT C. ADAMS, JR.
Chemical Engineer, U. S. Naval Engineering Experiment Station, Annapolis, Maryland

Between June 1931, and August 1933, the U. S. Naval Engineering Experiment Station was engaged upon an investigation of methods and means of boiler feedwater treatment. The object was to develop or to discover the method best suited to Naval use which would provide scale-free evaporative surfaces, corrosion prevention and desirable steaming conditions. A discussion of the methods and the results of the investigation and of the method of feedwater treatment adopted as a result was presented before the annual meeting of the American Society of Mechanical Engineers in December 1933.[1] The present paper reports subsequent experience with the Navy compound as used by certain vessels of the Fleet.

THE formula of Navy Boiler Compound 1933 is 47 per cent anhydrous disodium phosphate, 44 per cent soda ash and 9 per cent corn starch. These proportions were chosen after extensive tests in small experimental boilers had shown the mixture to be satisfactory under the most severe feedwater conditions disclosed by a survey of conditions throughout the Fleet. In order to make sure that the new methods would prove themselves completely satisfactory, the Bureau of Engineering arranged to have quarterly reports forwarded to the Engineering Experiment Station from forty-six selected vessels. These ships were chosen to include some on which there previously had been the greatest difficulty, as well as to include representatives of the various classes which make up the Fleet.

There was one difficulty in the interpretation of the reports which resulted from a confusion in the minds of some of the reporting officers. At the end of the first year of the investigation, in an effort to give an immediate improvement, instead of necessitating a delay of an additional year for the first benefit of the investigation, the proportion of di-sodium phosphate in the boiler compound was increased from ten to almost fifty per cent, and the soda ash and tannin percentages were decreased. Because of the inevitable delay in Government purchases and the necessity for expending the available stocks of the old compound, some ships did not obtain the modified compound until the fall of 1933.

The officers of the selected ships were asked to reply to six specific questions on the effect of the new method and to give such additional information as seemed pertinent. The questions were:

(*a*) What are the conditions as to scale formation or the removal of scale already in the boilers?
(*b*) Is there difficulty with formation of sludges or tendency to cloud gage glasses?
(*c*) Is there any tendency toward priming?
(*d*) What is the effect on corrosion?
(*e*) What method is used in treating feedwater and in making chemical analyses of boiler water?
(*f*) Are any difficulties experienced in the control of alkalinity?

Scale Formation and Scale Removal

Forty-five of the ships which reported stated that use of the compound either has decreased the rate of scale formation or has stopped scale formation altogether. Since some of these reports unwittingly dealt with the modified compound, it is obvious that the modification was a step in the right direction. The ships which are known to be using Navy Boiler Compound 1933 also record most satisfactory removal of the scale which was deposited previously.

The forty-sixth ship, which reported an increase in scale formation, is a heavy cruiser that for two or three years prior to August 1933, had used a proprietary material with satisfaction to the personnel. Although monthly reports to the Station during this period indicated that scale must be depositing in the boilers, the ship's personnel regularly offered such comments as "after over 4000 hrs of steaming, boilers continue to show no scale." As soon as the proprietary materials were discontinued and all ships were ordered to use the standard equipment and materials, this ship reported the formation of scale toward the burner end in all boilers. Many tube sections, samples of boiler water and reports, have been sent from the vessel to the Station. Careful examination indicates that the scale formation occurred prior to the change in treating methods, but that it was not discovered because of the uniform scale thickness and because upon being brushed the scale assumed a deceiving, metallic appearance. Upon the establishment of the positive chemical attack provided by Navy Boiler Compound 1933, disintegration of the scale commenced, resulting in unevenness in the scale surface, which permitted detection. When this ship reported at the end of September it was apparent that marked progress had been made in scale removal so that scale formation could not be in progress.

Formation of Sludges and Tendency to Cloud Gage Glasses

There was considerable variety in the replies to this question. The question was poorly worded and rather

* Abstract of paper presented at the Boiler Feedwater Session of the Annual Meeting of the American Society of Mechanical Engineers, December 3-7, 1934.
[1] Published in COMBUSTION, December 1933.

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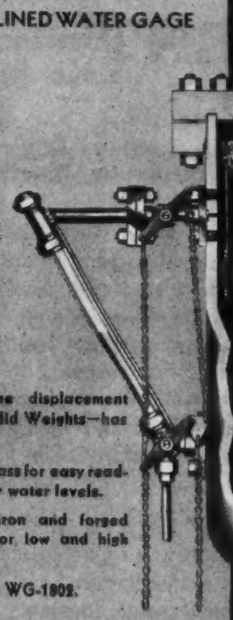

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confusing since some officers thought it referred to objectionable sludges in the boiler water and others reported on sludges found in the boilers when they were opened. The amount of sludge in the boilers was slightly greater than had been found after the use of the earlier compounds. On one destroyer, while there was a large amount of sludge in the bottom blow, there was none in the feed lines or feed heaters. Another noted that there had been present a large amount of sludge when the boilers first were inspected after the use of Navy Boiler Compound 1933 had been started. At subsequent inspections this sludge had been decreasing, which indicated gradual removal of the scale.

Over two-thirds of the ships reported no trouble from clouding of gage glasses. Ten ships reported "slight" or "unobjectionable" clouding and one of these qualified the report by stating that the slight tendency toward clouding was less than formerly had been experienced. The remaining ships described the clouding as the result of scale removal, stated that it occurred only in the first few days of use of the compound, and that a few surface blows cleared up this condition.

Tendency toward Priming

The ships were virtually unanimous in reporting the absence of any tendency toward priming. One destroyer reported priming when the new compound was first used, but that several bottom blows to remove suspended solids and reduce the alkalinity stopped the trouble. Two minesweepers, which operate in the same squadron, simultaneously sent in identical reports of the occurrence of excessive priming unless the alkalinity were reduced to 0.38 per cent normal. Subsequently, one of these ships was found to have a loose dry pipe, which was the cause of the priming.

Effect on Corrosion

In the matter of corrosion prevention the new methods of treatment have received an approval much more overwhelming than was expected. Twenty-six ships reported a decrease in corrosion over that previously experienced. Some qualified their comments by saying "slightly less." All of the destroyers were in this first group. Seventeen ships reported slight corrosion without making a comparison, or reported no change in corrosion. Only one stated that corrosive attack had increased since the change to revised methods and means of control. This ship is a very old, demilitarized vessel which probably suffers in efficiency from a severe reduction in complement. A comprehensive report on the nature and location of the corrosion showed it to be the result of dissolved oxygen in the feedwater selectively attacking the metal first to be freed of the old scale-coating. Corrective measures for preventing access of air to the boilers were suggested.

Methods Used in Treating and in Analyzing Boiler Water

The replies to this question show a decided effort on the part of ships' personnel to avail themselves of the new equipment and with it to maintain closer limits of control. Instead of being satisfied with the alkalinity range of 0.4 to 0.7 per cent of normal allowed by the revised regulations, the reports from twenty-seven, or almost two-thirds, of the reporting ships indicate an

effort to maintain closer control, preferably at the higher limit of alkalinity.

The need of individual treatment for the water in each boiler seems to be becoming more generally recognized, as evidenced by the reports of the various ways in which compound is added to the boilers.

Difficulties in Control of Alkalinity

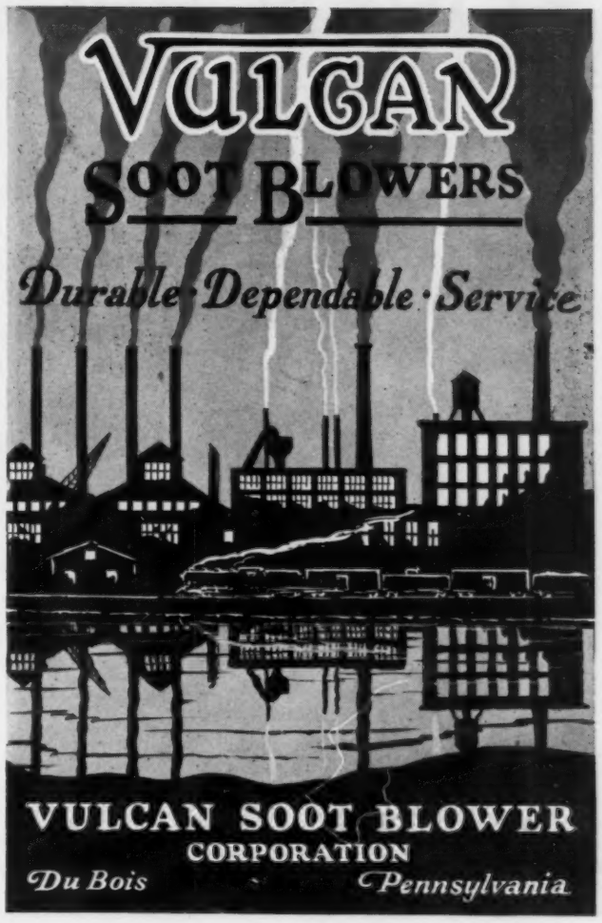
Thirty-six ships reported no difficulty with the control of alkalinity. The difficulties reported by the other ten were illuminating. In general, they indicated that the Naval boilers contained scale which Navy Boiler Compound 1933 attacked rapidly. A repair ship, a cruiser and a minesweeper reported on the rapid decline in alkalinity immediately after a boiler had been cleaned and refilled. This was interpreted to mean that the compound, which provides the alkalinity, was expended in decomposing scale already in the boiler. In furtherance of this belief a battleship reported that two or three days were required in which to build up or adjust the alkalinity of a refilled boiler. A hospital ship reported that much closer attention and almost daily doses were required to maintain boiler-water alkalinity.

Two ships commented upon difficulty in attaining zero hardness of the boiler water. It was to be expected in cases which required the removal of heavy scale that the phosphate of the compound would be expended first, leaving the alkalinity of the boiler water within the proper range but still without complete protection against scale formation. In such cases the recommended remedy, wasteful though it may seem, is to blow down, in order to remove the excess alkalinity, and then to add more compound, repeating the cycle until zero hardness is attained.

The most noticeable void in the reports is the lack of information and details of the chemical analysis of boiler water and the control of its composition. This was caused by the unfortunate delay in delivery of the newly designed cabinet, and by the generally damaged condition in which the glassware of the cabinets was found upon delivery.

Conclusions

The non-corrosive condition of boiler water treated with Navy Boiler Compound 1933, as almost unanimously reported from the Fleet, was somewhat surprising. When the new treatment was recommended for the Service, it was expected that reports similar to this single adverse one might be the rule. It was known that the ships did not have de-aeration equipment comparable to those now provided for shore power plants of equivalent size. There had been no appreciable difficulty from corrosion because of the protection afforded by scale coatings which existed in virtually every boiler. It was feared that the scale removal effected by Navy Boiler Compound 1933 would expose the boiler metal to corrosive attack. Several precautions in the care of feedwater were described in the Manual of Engineering Instructions to guard against severe attack of this nature. In spite of these mechanical precautions there was the possibility that the use of some chemical reducing agent might have to be included in the treatment. Fortunately the use of an oxygen-reducing chemical, with its attendant control and increased complexity of boiler-water treatment, now appears to be unnecessary.



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